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CONTENTS OF VOLUME I.

PLATES I-XLIX.

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GEOLOGY. VOL. I, No. 1.

THE GEOLOGY OF SANTA CATALINA ISLAND.

BY

WILLIAM SIDNEY TANGIER SMITH,

Candidate Ph. D., University of California.

WITH THREE PLATES.

Issued February 4, 1897.

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CONTENTS.

ERRATA.

P. 42, line 11 from the bottom, for "of," read "on."

P. 53, line 9, for "Plate III, fig. 1," read "Plate II, fig. 1."

P. 69, line 6 from the bottom, for "Plate III, fig. 1," read "Plate III, fig. 2."

P. 71, line 10, for "steam," read "stream."

P. 54, line 10. The statement that certain areas appear on the map without definite boundaries is not in accordance with the fact. Owing to a misunderstanding on the part of the lithographer, the areas in question are delimited by the usual dotted line.

January 12, 1897.

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I. INTRODUCTION.

1. LITERATURE.

THE existing literature bearing upon the geology of Santa Catalina is very limited, consisting of a short note in Whitney's Geology,[1] a brief report[2] and other scattered notes in the various Annual Reports of the State Mining Bureau, and a recent account of the topography of the island, by Prof. Lawson.[3] The report of the State Mining Bureau is not only superficial, but very inaccurate. In Whitney's report the absence of terraces is noted, contrasting with the neighboring islands, and the suggestion is made that this island may be sinking. Both of these points are elaborated

[1] Geol. Surv. of Cal., Geol., Vol. I, pp. 182–186.

[2] Tenth An. Rept., State Mineralogist, pp. 277–281.

[3] "The Post-Pliocene Diastrophism of the Coast of Southern California," by Andrew C. Lawson. Bull. Dept. Geol., Univ. Cal., Vol. I, No. 4, pp. 135–139.

by Prof. Lawson, who further calls attention to the older topography of this island.

2. GENERAL DESCRIPTION.

Santa Catalina Island, one of the group known as the Channel Islands, off the coast of southern California, lies about 20 miles south of San Pedro Hill, the nearest point on the mainland. At about the same distance south of Santa Catalina lies the island of San Clemente, the three elevations being nearly in a straight line.

The general trend of the island is northwest by west. Its length is approximately twenty-one miles, with an average width of three miles, varying from half a mile at the isthmus to about eight miles in the widest part. The prevailing winds are from west to southwest, and the waves exert their greatest force on the southwest face of the island. They are, however, by no means inactive on the landward side, as is shown by the rapidly retreating shore-line.

The only settlements on the island are the summer resort at Avalon, and a small community at the isthmus. Besides these, a few solitary houses are located at different points on the coast. The island was once occupied by Indians, and evidences of their camps occur frequently in the form of shell fragments, rounded stone implements, and earth blackened by the camp fires. Owing to its ruggedness and the scarcity of water, the island is habitable in only a few places. There are half a dozen or more springs and creeks which do not dry up during the summer, and a few wells supply the other points. All the water is decidedly alkaline.

The vegetation consists chiefly of herbage and shrubbery or underbrush, cactus forming an important part. The larger trees, except for a few dwarf oaks, are confined to the bottoms of the cañons. The summits, in general, are bare of everything except grass and cactus, but the majority of the slopes are thickly covered with an often impenetrable growth of scrub-oak, greasewood *(Adenostoma fasciculatum?)*, and elder, intermingled with cactus. It is note-

worthy that, in spite of the oftentimes luxuriant vegetation, the soil-covering is generally very thin, and the underlying formations are constantly exposed.

II. TOPOGRAPHY.

1. MAJOR FEATURES.

Main Ridge.—The island is traversed from end to end by a single main ridge, with branch ridges running out on either

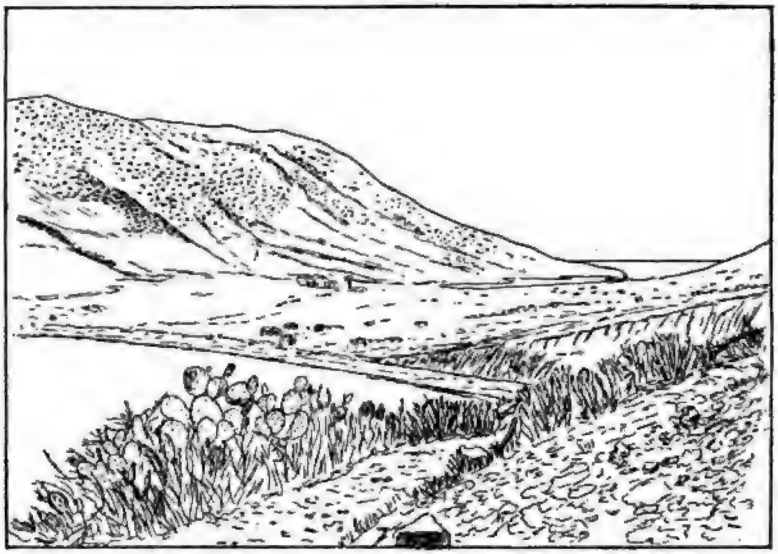

FIGURE 1—The Isthmus, looking south.

side. Beginning about a mile from the southeastern extremity of the island, this ridge makes a bold sweep around the head of Avalon Cañon to a point nearly west of Avalon. There it makes an abrupt turn, almost at right angles, and then follows very nearly the line of the northern coast, at an average distance of about a mile from the shore, till it reaches the isthmus. (See fig. 1.) This is a low divide, in the form of a saddle, with very gentle slopes. It has a length, between the bounding hills, of less than a quarter of a mile,

and its greatest elevation is about twenty feet. At either end of the isthmus the hills rise very abruptly to the main ridge, which is here from 800 to 900 feet in height. West of this point the ridge has two divisions, which unite, less than a mile and a half beyond, to form again a single ridge, continuing to the end of the island. On this end the ridge lies nearer the south than the north shore. One noticeable feature of this main watershed is the general uniformity of its height. For the greater part of its length the variations in altitude are not more than two or three hundred feet, the average elevation being about 1,400 feet. The two greatest elevations are near the center of the island, the peak known as "Orizaba" (or "Brush Mountain"), marked 2,109 feet on the map, and "Black Jack," the peak about a mile to the northeast of this, about a hundred feet lower.

Types of Topography.—The general character of the topography is very bold and rugged, and shows an advanced stage of development. A general view of the island from almost any point gives an impression of a close succession of sharp, steep ridges and V-shaped cañons. One of the most marked examples of this effect is in the slopes of Avalon Cañon, particularly on the west side, when seen from the opposite summits.

Viewed in detail, the island shows two prevailing forms of topographic relief: (1) the sharp ridges and V-shaped cañons just referred to, and (2) the rounded and level forms belonging to an older topography. The slope of the cañon walls, in the first type, is usually steep, occasionally having an angle of 40° or over. The first form is the prevailing one in most parts of the island, masking the remnants of the second.

The second type of topography is strongly contrasted with the first. It is found in the higher parts of the island, best developed in the eastern end. It is shown in the level character of the main ridge, and of several of the minor ridges which approximate it in altitude. These latter are (1) the principal ridges between Middle Ranch Cañon and

the main ridge bounding Avalon Cañon on the west; (2) the ridge connecting the main ridge with the point north of Whitley's Cove; and (3) a portion of each of the ridges running from the main ridge into the Little Harbor region (which comprises the semicircular area within a general radius of about three miles from Little Harbor).

In the lower portions of the Little Harbor region this second type of topography again appears. Within this area the tributary ridges, radiating from a central point not far from Little Harbor, rise to the higher slopes by a long, moderate incline. Beginning at the shore-line, with a cliff of from 200 to 300 feet, the rise above this is very gradual, till, at an average distance of a mile and a half from the water, a height of about 600 or 700 feet is reached. Beyond this the grade increases, and an altitude equal to that of the main ridge is soon reached, usually some little distance from the main ridge itself. Standing on the lower and more level portion of this area, and looking either toward the isthmus or in the opposite direction, one sees a great amphitheater, the distant ridges rising one above another, like gigantic tiers of seats, up to the main ridge. Were it not for the recent stream erosion we should thus have in the immediate neighborhood of Little Harbor an almost even surface, with a gentle seaward slope. The present drainage, however, has dissected this surface, cutting channels some of which, in their lower stretches, have a width of 100 yards or more, and a depth of perhaps 200 feet. In places the streams have made considerable deposits, and at a number of points these have been cut through, in very recent times, to a maximum depth of about twenty-five feet, at some distance from the shore.

Slope of Summits.—It has been seen that the main ridge and certain of the branch ridges are, in a general way, level in the direction of the length of the island. In those portions of the main ridge on either side of Avalon Cañon which are oblique to the trend of the island, the generally level summits are seen to slope at an angle of a little over

one degree toward the northern shore. (See figs. 2 and 3.) In fig. 2, Black Jack and Orizaba and a portion of the ridge between Silver and Middle Ranch Cañons are seen above the main ridge. At the "west end" (that por-

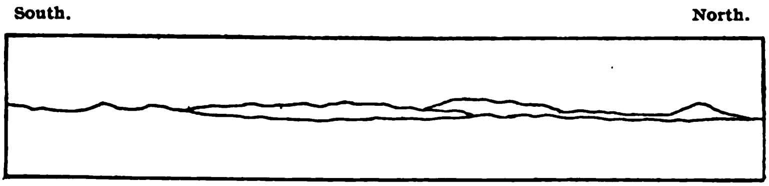

FIGURE 2—Outline of the summit of the main ridge west of Avalon Cañon, as seen from the summit of the ridge on the opposite side of the cañon.

tion of the island west of the isthmus), the more northerly of the two branches of the main ridge has an average height throughout its length, about 200 feet lower than the other. Thus it appears that in transverse section the island shows a general slope toward the mainland.

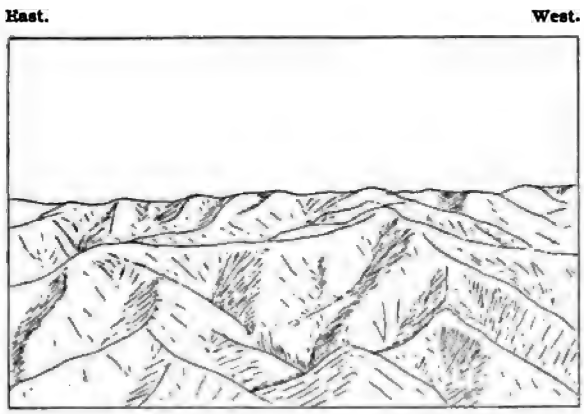

FIGURE 3—Outline of the summit of the main ridge south of Avalon Cañon, as seen from the summit of the ridge on the opposite side of the cañon.

Two Types of Drainage.—The principal stream cañons running from the main watershed are of two types, which may be readily distinguished on the map. Those cañons which have their mouths on the northern or landward coast

are broad and open stream valleys, while those running down to the opposite shore have a long and trough-like character which they preserve to the shore-line. These two types are quite pronounced over all the southeastern division of the island, while at the isthmus the two harbors —which are merely submerged stream valleys—still show the same contrast. In the western end this characteristic, though still evident, is not so marked. The narrow, trough-like cañons are occasionally somewhat broader in their upper portions than near their mouths, where they are frequently mere rocky gorges. The most pronounced example of the narrow type is Silver Cañon, whose walls near the mouth rise to a height of over 1,000 feet, while the distance between them at the base is in places not more than from twenty-five to a hundred feet. The length of this cañon is about three miles. Avalon Cañon, a good example of the other type, has a length of about two miles, with a mean width, from watershed to watershed, of somewhat more than that. From the main ridge on either side a great number of rather short and steep V-shaped cañons are tributary to the main valley, these stream beds making the descent of 1,200 or 1,400 feet within an average distance of about a mile.

All the forms of topography thus far described are largely independent of the material from which they are carved; that is, variation in the character of the rocks has but little connection with variation in topographic form.

2. MINOR FEATURES.

Echo Lake.—There is one small lake on the island, situated about a mile to the northeast of Black Jack, at an altitude of about 1,300 feet. This belongs to the class of ephemeral lakes. Visiting it two summers in succession, at the same season, the writer found it, the first time, a shallow pond about 100 yards long, while the next year it was entirely dry. It is a small drainage lake, without outlet, probably shut in by faulting.

Sea Cliffs.—Except for the openings formed by the cañon mouths, cliffs surround the island on all sides, running from one or two hundred feet to 1,400 feet or more in height. The boldest and highest cliffs are found at the west end, and between Silver Cañon and the southeastern extremity of the island. The highest of all are just to the east of Silver Cañon, where the waves have cut across the end of a minor ridge whose altitude equals that of the main ridge. These cliffs, although furnishing excellent geological sections, are wholly inaccessible at nearly all points, owing to their height, the angle at which they meet the water, and the absence of beaches.

The cliffs are rapidly receding, in many cases more rapidly than the streams which trench their surfaces can cut down their channels. This is shown by the V-shaped openings on the face of the cliff, from 50 to 200 feet or more above the water. Such are the mouths of the cañons draining the southern slopes of the main ridge at the head of Avalon Cañon. These open on the southern coast, about two miles to the east of the entrance to Silver Cañon. The rapidity of the cliff-cutting here will appear the more remarkable when it is known that these streams, though draining comparatively small areas, are torrential in character. It must, however, be remembered that they are active only during the rainy season.[1]

In addition to these larger V-shaped openings, several smaller ones were seen along the higher parts of the cliff, less than a mile to the east of the entrance to Silver Cañon. These, from the water side, present the appearance of a stream draining outward over the face of the cliff. From above, however, it is seen that the drainage is inland, toward Silver Cañon. This phenomenon is due to the cutting back

[1] A phenomenon similar to that above described has been observed by the writer at several points along the California coast between Port Harford and Santa Monica. Here the recent streams have carved narrow channels in the surface of the lowest terraces which border the shore, and have formed clear-cut V's on their upper edge. The cause here (unlike that in the case of Santa Catalina) is, no doubt, that an insufficient time has elapsed, since the elevation of the coast, for the streams to deepen their channels further.

of the watershed so rapidly that the drainage has not had time to adjust itself to the changed conditions.

Bays.—The coast of the island, particularly on the landward side, is indented with numerous bays. On the north side, partly on account of less active cutting along the coast, and partly on account of the more open cañons whose submergence has produced the bays, they are wider, and generally furnish safe landing places. On the other side of the island, although there are numerous recesses in the shore-line (particularly of the west end), these openings are generally surrounded by high cliffs, and there are only two bays, Catalina Harbor at the isthmus, and Little Harbor.

Beaches.—Several cañons on the south side of the island, while not forming bays, have beaches at their mouths. In many cases, both here and on the northern coast, the beaches have been built up by wave action so as to form along the shore a barrier from five to ten feet higher than the area just behind. The beaches, in general, consist of coarse, well rounded, and flattened shingle, though one or two exceptions were seen where the beach was largely composed of a rather fine sand. Apart from the beaches which mark the entrance to the larger cañons, there are a few very narrow beaches for short stretches at the base of the cliffs, only on the landward side. These are in general accessible only at low water.

The beaches as a rule are curved in outline, concave toward the ocean. A marked exception to this is seen in the projecting, tongue-like, Pebbly Beach. This has been built up by the opposing action of two series of waves, which, coming from either direction along the coast, meet at this point. Not only does the beach exhibit the barrier-like character mentioned above, but its outer surface shows a series of narrow terraces formed by the waves. As many as six were seen at one point.

Another form is shown in the hook which marks the entrance to Catalina Harbor, and is known as Ballast Point. This is built of coarse shingle, some of the material compos-

ing it having a diameter of about a foot. High winds blow daily through the narrow pass at the isthmus, causing a strong inward current, which is gradually bringing about a shoaling of the harbor. Thus here, as at Pebbly Beach, the accumulation of shore-drift, through the action of waves and currents, has more than kept pace with the sinking of the island.

Terraces.—The pronounced contrast which Santa Catalina presents in its topography, not only to the adjacent land areas, but to the greater part of the coast of California, has already been shown by Prof. Lawson.[1] The most striking difference is in the marked absence, on this island, of the terraces which are so clear-cut and pronounced on the slopes of San Pedro Hill and San Clemente. With but two exceptions, Santa Catalina is devoid of any evident terracing from one end to the other. The terrace-like character of the lower levels of the Little Harbor region (already described) forms one of these exceptions. That this is, in part, at least, of the nature of a true terrace, is shown by the nearly level character of the various ridges in their lower parts, their gentle seaward slope, the change in grade at the rear, at an altitude of 600 or 700 feet, the planing off of the upturned beds of the basement series, with rolled pebbles scattered over the lower slopes of the andesite, besides more or less sandstone and conglomerate on these slopes bordering Middle Ranch Cañon. All these point to a time when this region contained a bay, into an arm of which a stream, doubtless an older form of that which now drains Middle Ranch Cañon, brought the deposits just mentioned (shown on the map). It is possible that there is, besides this, a series of such terraces within this area. If so they are not strongly marked, and the fact could only be established by a more detailed observation than the writer had time for. Terracing similar to that found here must at one time have ex-

[1] "The Post-Pliocene Diastrophism of the Coast of Southern California," by Andrew C. Lawson. Bull. Dept. Geol., Univ. Cal., Vol. I, No. 4, pp. 135–139.

tended along the cliffs bordering the island,[1] but it has been since removed by a prolonged period of active cliff erosion. That the evidence is preserved here is due to the fact that the terracing extended so far inland. This belongs to an earlier period than the terraces of the main coast and of San Clemente.

The other terraced structure occurs in the cañon back of

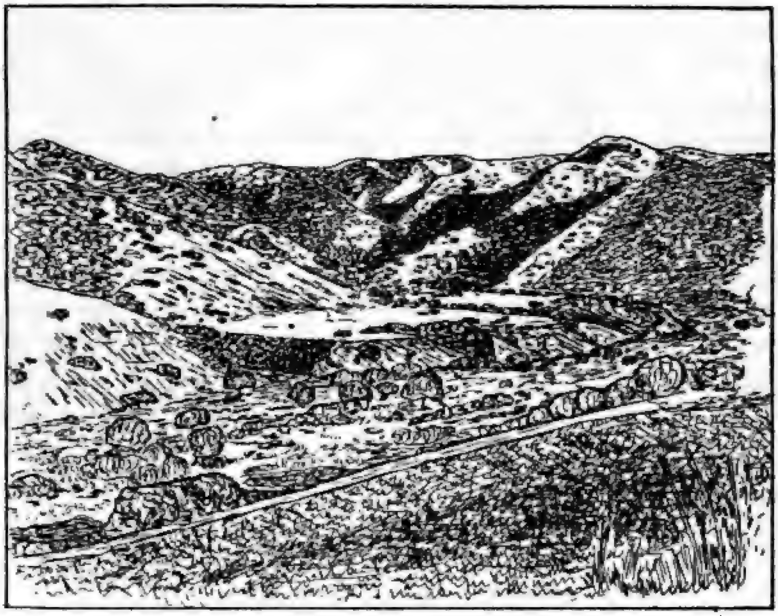

FIGURE 4—Dissected alluvial fan, southeast side of Avalon Cañon.

Avalon (see fig. 4), about half a mile from the shore-line, and is seen on both sides of the cañon—which is about a quarter of a mile wide at this point—as a broad platform extending up some distance into the cañon-like opening on either side of the main valley. Its front edge has a gentle seaward slope, while from front to rear it rises gradually toward the hills. A sharp ascent of about forty or fifty feet marks the

[1] Rolled pebbles were found scattered over a small area near the southeastern end of the island, at an altitude of 1,000 feet; also on the main ridge south of Avalon Cañon, at about 1,400 feet; but the remains of an Indian camp within a hundred feet, in each case, made the evidence doubtful. In neither case, however, were any pebbles found among the remains marking the camp.

front of the platforms on either side of the cañon. Streams have cut into the surface and along the sides, forming several comparatively broad watercourses. Some of these streams have not yet reached the level of the main cañon where they debouch upon it, and have formed small, rather low and broad alluvial fans beyond their mouths.

The material composing the platforms consists of both rounded and angular fragments. From the form of the structures and the form and arrangement of their material, it is evident that we have here, not a stream terrace, as its appearance might at first indicate, but undoubted alluvial fans.[1] These have been dissected and cut away in recent geological times, owing to the drowning of the stream valley at Avalon, with a consequent shortening of the stream courses, and a deepening of the channels.

III. GEOLOGY.

The basement series of Santa Catalina consists of crystalline metamorphic rocks, principally quartzite. This series, with the hornblendic rocks, the talc-schist and the serpentine, covers in a general way the whole western half of the island. Besides the main occurrence, there are patches of these rocks along the main ridge to the west of Avalon Cañon. The basement rocks are cut by occasional dikes, which are principally at the west end, and have a general northeasterly trend.

The eastern end of the island is occupied by diorite and porphyrite. Bordering this area on the north, and of later age, is an area consisting of numerous flows of andesite, of which there are several other smaller occurrences besides. A particularly interesting area of these rocks is found to the east of Isthmus Cove, where, interbedded with the volcanics, is seen a band of tuff and diatomaceous earth.

The lower slopes of the andesites in the Little Harbor

[1]Alluvial fans are by no means uncommon on the island, but no other case presents any similar terracing.

region are covered with rolled pebbles, with several patches of sedimentary deposits. In the eastern portion of the Little Harbor region is a small area of rhyolite, which was not found elsewhere. A narrow strip of quartzite breccia occurs at the southeastern extremity of the island.

A. ERUPTIVE ROCKS.

I. DIORITE.

There are three observed occurrences of the diorite: one along the cliff bordering the shore just to the north of Avalon, the second near the head of the cañon back of Pebbly Beach, and the third in the lower portion of Silver Cañon. These are apparently dikes of considerable width.

Macroscopic Characters.—The diorite is coarse-grained, and of a light grayish color, more or less mottled. The specific gravity of a specimen from Silver Cañon was found to be 2.777. In the coarser-grained specimens the separate minerals may easily be seen without recourse to a lens. With the lens the rock is seen to be composed of a ferromagnesian mineral, feldspar and a varying amount of quartz.

The feldspars range from a somewhat glassy condition to one in which they are whitish and more or less opaque. They constitute, in general, the principal mineral of the diorite. The ferromagnesian mineral is hornblende, dark green in color, and altered in part to chlorite. This mineral varies in amount from a little less than one-half to perhaps one-fifth of the surface area. Besides the hornblende an occasional leaflet of biotite was seen in the specimens from near Avalon, and also in one or two from Silver Cañon. The quartz usually occurs in small areas scattered throughout the mass of the rock. In addition to these, magnetite is apparent in nearly all the hand-specimens of the coarser-grained varieties, being rather conspicuous in one specimen from the cañon back of Pebbly Beach.

Microscopic Characters.—Under the microscope the diorites are found to have a nearly even-grained, holocrystalline structure, and to be composed essentially of a lime-soda-feldspar, hornblende and occasional biotite, with free quartz always present in varying amounts. Augite is also present in some of the slides, and in nearly all magnetite is an important constituent. No apatite was observed in any of the sections. There is an occasional tendency to a porphyritic development among the feldspars. Mineralogically considered, the rock is a quartz-hornblende-diorite, with a tendency to lath-shaped forms among the feldspars.

The feldspars are in general allotriomorphic, and tend to develop crystal faces only occasionally, where they come in contact with quartz. In some of the slides many of the feldspars are fairly clear and free from inclusions or decomposition products. Aside from these the majority are clouded by alteration products, which, in some cases, have partly or wholly obliterated the traces of the twinning lamellæ, which are clearly shown in the fresher material. This cloudiness is apparently due in part to a kaolinization of the plagioclase, but also to calcite, which occurs in small, irregular patches and threads in many of the sections. This product is also found, in some instances, in lines along the twinning planes. Twinning takes place according to the Carlsbad, albite and pericline laws. Pericline twinning is the least frequent, and is usually seen under crossed nicols as a series of very fine lines.

Excellent zonal structure is occasionally seen, but is infrequent. The varying optical orientation in such cases shows that the mineral grows more acid from the center outward. Inclusions in the feldspars are not common, but rarely one of the largest crystals contains from one to a number of smaller feldspars which are without definite orientation toward their host, and without good crystal boundaries. Inclusions of small ragged flakes of hornblende or chloritic material are of much more frequent occurrence. Several feldspars occur packed with small, irregularly bounded sections of what appears to be primary hornblende.

The structure in this case is micropoikilitic. Occasionally sections contain numerous brightly polarizing, microscopic needles, doubtless of hornblende.

Besides the decomposition products already mentioned, more or less epidote is usually present, generally in small irregular patches.

All the diorites have doubtless been subject to stresses since they were consolidated, but only the rocks from Silver Cañon give any marked microscopic evidence of it. In these rocks the feldspars seem to have been particularly affected, the hornblende and quartz showing little or no evidence of strain. The evidence here is of three kinds—altered optical properties, bent crystals and fractures, which may or may not cause displacements. The extinction of the feldspars is frequently very indefinite and variable. Comparatively few of them show good extinction, and even these are sometimes considerably affected by cracks. In the others strain shadows take the place of the normal extinction. Bent crystals are not common, but a few of the sections show a distinct curvature, and a corresponding alteration in extinction. The fractures referred to are not the cracks frequently found in single individuals, but more extensive ones passing from crystal to crystal, simply as cracks, or forming veins which have been filled with secondary matter. A few veins were found, the most pronounced one extending irregularly half through a slide, some of the feldspars on either side having suffered slight displacement. This vein is .05 mm. in width, and is filled principally with calcite, with more or less chlorite and quartz.

From the extinction angles on either side of the albite lamellæ, in favorable sections, the plagioclase appears to lie between a basic oligoclase and an acid labradorite.

From its relations to the quartz and feldspars, the hornblende seems to have been the first mineral in the order of the crystallization of the essential constituents of the diorite. The relations of quartz and feldspar show that a part of the feldspar was formed before, and part at the same time with

the quartz. The simultaneous development with the quartz is evidenced by a frequent irregular intergrowth along the boundary line of the two minerals, and further by the occasional development of micropegmatitic structure.

Quartz occurs in somewhat smaller individuals than do the feldspars. It is most frequently found in aggregations or in lines, as if, being the last mineral to form, it had filled the spaces between those previously existing. It is present in varying amount in all the slides, being fairly abundant in some, amounting to perhaps one-fourth of the total minerals of the slide. The sections vary in size from about .1 mm. to about 1.2 mm. It occurs in allotriomorphic forms, usually with very irregular outlines, the sections being frequently somewhat intergrown on the margins. The sections are usually clear. Most of them contain liquid inclusions, occurring usually without any definite arrangement, though occasionally they are seen in lines extending through several sections. Besides these there may be seen with the higher powers occasional minute, greenish needles, and sections having the form of cross-sections of hornblende. They are without noticeable polarization. The quartz also contains occasional magnetite.

The hornblende occurs in sections with very irregular boundaries, due to resorption. No approach to crystal forms was seen. The feldspar is always moulded on the hornblende, except in one case observed. In this section a small crystal of feldspar was seen apparently projecting into one side of the hornblende, the feldspar showing good crystal boundaries where surrounded by the hornblende. Aside from this instance the hornblendes contain no inclusions of feldspar, while the feldspars contain occasional inclusions of hornblendic material. The smaller feldspars are doubtless, in part, at least, contemporaneous with the hornblendes, though the feldspars in general are later. In size the former compare favorably with the feldspars. Twinning parallel to the orthopinacoid is common in the larger and fresher sections. The pleochroism is pronounced,

𝔠 being green, 𝔟 yellowish brown, and 𝔞 pale yellow-green to almost colorless. The absorption formula is $\mathfrak{c} > \mathfrak{b} > \mathfrak{a}$. Inclusions are not common and are principally magnetite. There is an occasional intergrowth with biotite. The alteration of the hornblende is well advanced in many of the slides. It appears to be undergoing a uralitic change by which it is transformed into a dirty greenish, fibrous aggregate, much like "reedy hornblende," with a rather weak pleochroism. This secondary hornblende has usually a parallel arrangement of its fibres, and the terminals of the sections are generally more or less ragged. It also occurs in finely fibrous, irregular areas, with the fibres irregularly oriented. A further alteration of the hornblende is mainly into chlorite and calcite.

Biotite is not common, though occasionally found. The sections are strongly pleochroic, always show irregular boundaries, and the mineral occurs either alone or intergrown with hornblende. The biotite is in part altered to chlorite, and some of its sections are wholly surrounded by a chloritic margin. No inclusions occur, except occasional grains of magnetite.

Augite is present in some of the slides, being variable in amount, but at times forming an important constituent. It generally presents very irregular boundaries, but several sections were seen showing roughly the crystal form characteristic of cross-sections of augite. It has a granular, much broken appearance, and a high refractive index. Its most characteristic feature is a clouding of the area by an opaque, dirty-brown decomposition product. Few of the sections were free from this product, and it marked the mineral wherever found. The augite is practically colorless, and is without any sensible pleochroism. No cleavage was observed anywhere, and only one case of twinning. Whereever the augite comes in contact with the hornblende the boundary line is sharp and clear. When it occurs in isolated sections these are usually free from the uralitic product described in connection with the hornblende. This, together with the freedom of all the hornblende areas from

the cloudy decomposition product of the augite, naturally leads to the conclusion that none of the fibrous hornblende comes from the augite.

Magnetite is found in all the slides, though not in any considerable amount. It occurs as inclusions in the other minerals, and is generally in the form of grains frequently showing partial crystal boundaries. In size they range up to .3 mm. Besides the grains, there are several very irregular areas of considerable size—up to 2 mm. or more in length—in or near the areas of the ferromagnesian minerals.

2. PORPHYRITE.

Following the usage of Iddings[1] the term "porphyrite" is here used to include those rocks which are characterized by a medium-grained porphyritic structure, and which contain among their essential constituents a lime-soda-feldspar. They constitute the connecting link, as it were, between the deep-seated diorites on the one hand, and the surficial andesitic rocks on the other, and pass by insensible gradations into either. The physical conditions attending and controlling its crystallization are the prime factor in determining the position of the rock in the scheme of classification.

Occurrence.—The porphyrite occurs in a single large area in the southeastern part of the island, and was not found elsewhere by the writer, except as smaller masses in the form of dikes. The main area has an average width of about three miles, with an extreme length of about nine. It is cut by dikes of porphyrite and diorite, from two to thirty feet or more in width, which are shown on the cliffs at a number of places along the shore.

Character.—The rocks are very much weathered, and even those specimens which appeared to be fairly fresh were seen, when examined microscopically, to be considerably altered. In weathering the rocks first break into coarse,

[1] Twelfth An. Rept. U. S. Geol. Surv., Part I, pp. 582–584.

irregular, block-like forms, looking, in some cases along the shore near Avalon, like square pillars projecting from the side of the cliff. These break up into smaller block-like masses, and the process is continued until the gravelly condition is reached. On the hill slopes the projecting masses frequently present similar forms with smooth surfaces, but it is not uncommon to see also small, boss-like projections, with rough, uneven surfaces. The cause of this difference in form is doubtless a variation in the grain of the rock. The soil formed from these rocks is generally of a dull, yellowish color. The porphyrite contains the same minerals that occur in the diorite, except biotite, which was not seen in any of the slides. It presents the same general characters wherever found.

Macroscopic Characters.—The color of both the unaltered and weathered porphyrite is much the same as that of the diorite, the fresh hand-specimens varying from light to dark gray, most of them with a tinge of green. Little can be made out in the fresher specimens with the unaided eye, except an occasional feldspar, shown by the reflection from a cleavage surface. Hornblende crystals of some length—up to 5 mm. or more—are developed in one or two specimens. As the rock weathers the whitening of the feldspars usually brings out plainly the porphyritic structure. With the lens the porphyritic feldspars may occasionally be distinguished from the medium-grained ground-mass, though these are usually masked more or less by the fracture of the rock, which leaves minute flakes or splinters clinging to the surface of the specimen. The rock frequently presents a slightly mottled surface, in the dark and light colors. Gleaming bits of pyrite may occasionally be seen in some of the specimens.

Microscopic Characters.—Microscopically the rock is holocrystalline and porphyritic, with phenocrysts of a lime-soda-feldspar and of hornblende—occasionally also of augite—and a medium-grained granular ground-mass, composed essentially of feldspar and quartz. The phenocrysts vary con-

siderably in number. In some slides there are comparatively few, while in others they constitute the larger portion of the slide. The ground-mass is never glassy, and does not show any flow structure, except to a slight extent in specimens from one or two dikes. Quartz is seen sometimes among the phenocrysts, though this is a very rare occurrence. Magnetite occurs as an accessory, but usually in very small amounts. No apatite was seen, and in the rock of which the analysis is given below no phosphorus was found. Most sections show little evidence of disturbance.

The porphyritic feldspars occur in idiomorphic forms, which are somewhat tabular parallel to the brachypinacoid. The majority of the crystals show good boundaries, except where their growth was interfered with by the growth of other phenocrysts. Many of the sections, however, show boundaries which are more or less irregular or rounded, and due, in part, at least, to resorption. The sections vary in size from about .2 mm. to nearly 3 mm. Zoning is common. The twinning is in accordance with the albite and Carlsbad laws. Pericline twinning rarely occurs. As in the diorite, the feldspar lies between a basic oligoclase and an acid labradorite. Many of the sections are considerably cracked. Some of the feldspars are fairly fresh, but most of them are more or less clouded by decomposition products. This cloudiness is due largely to a kaolinization of the mineral. Considerable areas are sometimes altered to calcite, with more or less epidote. The decomposition is such at times as to destroy, partly or wholly, the traces of twinning. Occasional inclusions of hornblende or chlorite are seen in the feldspars. One section was seen with a zone of chloritic material not far from the boundary, arranged in threads and fibres parallel to the longer direction of the feldspar. Small magnetite grains are rarely included in the feldspar.

The hornblende is prismatic in habit, and usually either shows resorbed boundaries, or the original outlines are more or less obliterated by alteration products. No terminal planes were seen in any section. In two or three of the slides

the characteristic lozenge-shaped cross-sections were seen, with a distinct prismatic cleavage. Twinning is common, parallel to the orthopinacoid. Comparatively few unaltered sections were found, most of the hornblende which was originally present in the slides having been altered to chlorite and calcite. In some of the slides the hornblende is wholly replaced by secondary minerals. The freshest sections are frequently surrounded by a chloritic border, or decomposition has begun along cracks and cleavage planes. The pleochroism of both chlorite and hornblende is the same as in the diorites. The hornblende in some cases has the fibrous character described under the diorites. In one slide in which this fibrous hornblende occurs, without good crystal boundaries, there is another secondary hornblende, with different optical properties, and having the form characteristic of augite.

From what has been said it will be seen that hornblende is a primary constituent of the rock. It is also the dominant ferromagnesian mineral. Roughly estimated, it constitutes, with its decomposition products, about one-fourth or one-third of the total amount of minerals in the slides.

Augite is found in varying amounts in nearly all the slides, usually in the form of irregular grains, or as irregular brownish or more or less opaque patches. It has the same general structure and habit as in the diorite and its decomposition products are similar. Usually it has a very insignificant position compared with the other minerals of the rock. In two or three of the slides, however, it compares in amount with the hornblende, and in one slide in particular—from a specimen from the cañon back of Avalon—the sections, though rather small, are quite numerous, constituting perhaps one-fifth or one-fourth of the total minerals of the slide. Here the mineral is fairly fresh and free from decomposition products.

It is almost colorless or pale green, and without pleochroism. When any crystal boundaries are shown they are only partial. The form when developed shows the usual octagonal cross-section. The crystals occur as separate

individuals. The feldspars are molded on the augites, and sometimes completely enclose the smaller sections. The augite shows no definite cleavage, but is usually more or less traversed by cracks. In this slide no hornblende was seen, though there are considerable areas of chlorite. No doubt hornblende was at one time present, being now represented by the chlorite, for the augite in the slide has no border of chlorite, nor is the latter seen along the cracks of that mineral. When near or touching chloritic areas the augites have as sharp boundaries and appear quite as fresh as those sections which have no chlorite near them. In weathering the augite alters to a granular, dirty brownish product, more or less opaque. In one slide, from the northern side of Avalon cañon, what was originally augite with a short prismatic habit, is entirely altered to hornblende (see page 22). The sections are idiomorphic, with the forms characteristic of augite, but with the cleavage of hornblende. In vertical sections the cleavage is very pronounced, showing in part as open cracks. This hornblende is pleochroic, $\mathfrak{a}$ being a very pale yellow, $\mathfrak{b}$ pale yellowish green, $\mathfrak{c}$ greenish brown. The mineral is more or less dull in appearance, and the polarization colors are not clear. It is quite unlike the fibrous hornblende in character. One of the sections shows indistinct twinning lamellæ parallel to the orthopinacoid. The augites contain as inclusions occasional magnetite grains.

The magnetite varies greatly in amount, being almost entirely absent from some of the sections. In the rock containing abundant augite there is considerable magnetite in small, irregular patches or needle-like forms, at times in or cutting across the feldspars, or projecting into the augites. One slide from Pebbly Beach shows a few small grains with the crystal form of magnetite, but altered to limonite.

The granular ground-mass of the porphyrite is composed of usually allotriomorphic feldspar and quartz, the larger proportion being of the former. At times, however, the feldspars tend to lath-shaped or rectangular forms. The borders of the grains in the ground-mass frequently inter-

lock. Occasionally small, ragged flakes of hornblende or small patches of chlorite occur. The minerals of the ground-mass, in those slides showing the most pronounced porphyritic structure, have a diameter of from .03 mm. to .1 mm. As the size of the grains increases the rock assumes the structure of diorite-porphyrite, with occasional, though rare, porphyritic quartzes. All gradations were found between porphyrite and diorite.

The quartz varies considerably in amount in the porphyritic rocks. Usually it is rather subordinate, but occasionally it is quite abundant, forming perhaps one-fourth of the minerals of the slide. These rocks, however, are not common, and are doubtless only local developments. One slide of the diorite-porphyrite is remarkable for the manner in which the quartz is developed with respect to the other minerals. This rock (from the slopes to the west of the entrance to Silver Cañon) contains abundant phenocrysts of feldspar, with porphyritically developed quartz. Under crossed nicols the quartz appears as scattered and more or less rounded grains. Occasionally several of these are found near together, showing similar polarization colors and a common extinction. On revolving the stage it is seen that the rounded borders do not mark the limit of the sections of quartz; for the extinction of the mineral shows that it has an outer zone which has a pronounced micropoikilitic structure, being closely packed with finely polarizing feldspars. The quartz occasionally shows a crystal form. The ground-mass of the rock is coarsely crystalline and consists largely of micropoikilitic quartz similar to the larger sections, but without clear centers. A very few of the larger sections also are wholly filled with feldspar aggregates. The clear centers together with the micropoikilitic margins indicate arrested development of the quartz, which began to form before the growth of the minute feldspars, the latter forming before the final crystallization of the quartz. The rock is much altered, and except in one or two instances the traces of twinning in the feldspar phenocrysts are wholly

obliterated by decomposition products. Hornblende is wholly replaced by chloritic material.

Analysis.—The porphyrite was nowhere found in an entirely fresh condition. The following analysis was made from the freshest specimen obtained, as shown by its thin section:

	I.	II.
SiO_2	63.82	65.71
TiO_2	trace	
Al_2O_3	16.53	17.08
Fe_2O_3	1.28	2.84
FeO	2.93	1.79
MnO	trace	
CaO	5.57	5.24
MgO	1.99	2.57
Na_2O	4.12	3.87
K_2O	.77	1.02
H_2O	1.82	
P_2O_5	....	
CO_2	1.10	
	99.93	100.12
Sp. gr.	2.689	

I. Porphyrite from Pebbly Beach, Santa Catalina.
II. Quartz-diorite, Dognaska. (Banatite.)

The analysis of the porphyrite differs but little from that of the banatite given above. In some of its aspects the diorite is not much unlike the microscopic character of some of the banatites.

Inliers of Basement Rocks.—At a number of points in the porphyrite area, following the general direction of the main ridge to the west of Avalon, and along a line extending from the coast northwest of Avalon to near the coast east of Silver Cañon, there occur at intervals patches of the basement rocks. These are found not only along the main crest, but on several of the branch ridges to the west and northwest of Avalon, and on one of the branches running into Silver Cañon. They also occur at irregular intervals at the base of the cliffs, from Avalon Harbor for a distance of about a mile to the northwest. The outcrops along the ridges vary from a few yards to nearly 200 feet in length.

Only the largest have been indicated on the map (even those being necessarily made on a larger scale than that of the map), where they are shown as quartzite, though also including rocks from all the basement series. Those in the cliff sections occur as definite inclusions, and vary in length from a fraction of an inch to about 50 feet. The porphyrite in other places also contains inclusions, though nowhere are they so abundant as at the points mentioned.

It is possible that some of the outcrops along the ridges are remnants of a former covering to the porphyrite, but undoubtedly some (if not all) of them exist as inclusions within the igneous rock, as do the occurrences along the shore; for some of them occur in saddles along the main ridge, while those on the minor ridges are in great part hundreds of feet below the average altitude of the main ridge. To contain such large inclusions an intrusive of considerable size must be predicated. This, together with the size and form of the area of the porphyrite, points to its origin as a laccolite.[1] The microscopical character of the rock, together with its mode of occurrence, clearly indicates its intrusive nature.

The mass of the porphyrite appears to be roughly dome-shaped, with a somewhat elliptical base, and though no remnant of a cover was found it cannot be doubted that one formerly existed, now removed by extensive and active erosion. The base of the mass was not seen at any point.

Porphyrite Dikes.—Occasional dikes penetrate both the porphyrite area and that of the quartzite, the latter at the west end particularly. At the mouth of Silver Cañon the diorite, also, is cut by porphyrite dikes, one of which contains numerous inclusions of the diorite. Wherever the directions of the dikes could be determined they were found to be nearly vertical, or within 20° of the perpendicular, and approximately

[1] The term "laccolite" is here used in the sense of a somewhat dome-shaped mass which has been intruded into a yielding body of rock, not necessarily along the bedding planes. On this view the undisturbed condition of the beds previous to the intrusion is of minor importance, the main factors being the possession of basement and cover, and the dome-shaped form of the mass.

parallel, the range being from N. 25° E. to N. 65° E. Probably all of these dikes are of nearly the same age as the porphyrite, though many, or possibly most of them, are a little later, judging from the fact that the area of the porphyrite itself is penetrated by them. Most of the specimens obtained are very much altered, and contain a comparatively large amount of calcite, but there is enough of the original structure left to show definitely that the rocks are porphyrite. In general nothing further than this could be determined, though most of the specimens appear to be not much unlike the rocks of the main mass.

A somewhat different structure is shown in two or three of the slides, only one of which will be described. This is from a dike on the northern coast, at a point about a third of the distance from the isthmus to the extreme northwestern end of the island. The dike is nearly vertical, and has a width of eight feet. Specimens were taken from near the margin and central portion of this dike, the two being entirely different in appearance. That from near the center is a pale, even gray, while the other is a darker, mottled gray, with an intergrowth of light and dark areas. The darker parts appear to be compressed in a given plane, and, as seen with a lens, have usually a minute central cavity. The rock from the middle of the dike also contains here and there very minute thread-like cavities.

Although the hand-specimens differ so much in general appearance the contrast is not so great under the microscope. Phenocrysts are not very numerous and are wholly of labradorite, which is quite fresh. They are considerably resorbed, and seldom show crystal boundaries. The ground-mass is almost wholly filled with lath-shaped feldspar microlites of various sizes, which show a pronounced flow structure in the slide of the marginal rock, this being less noticeable in the specimen from the center. A majority of these microlites have indented terminals. In the marginal rock slide there are two distinct types of areas in the ground-mass, in both of which microlites occur, one somewhat yellowish, and the other dark in color, from minute particles contained in

it. In the first type the finer portion of the ground-mass has a microcrystalline structure. In the other case the matrix is largely isotropic, and is principally of secondary silica in the form of opal. These latter areas have usually a small irregular central cavity somewhat rounded or oblong in shape. In some cases these centers have been filled with secondary quartz. These darker areas of secondary silica are usually separated from the lighter ones by an irregular and generally narrow band of a yellowish green, showing high polarization colors. Under crossed nicols and with higher powers, this is seen to be composed of finely polarizing aggregates, doubtless of some secondary ferromagnesian mineral. Similar minute, radial aggregates occur scattered through the lighter areas of the slide.

The slide from the central portion of the dike does not show the division into light and dark areas, though it contains a small amount of opaline silica and quartz. There is a larger amount of the greenish yellow ferromagnesian mineral, which is more evenly distributed through the rock, a part in the form of radial aggregates and a part as minute flakes. The matrix is cryptocrystalline, showing a feeble polarization. The ground-mass is filled with opaque, dust-like, microscopic particles.

3. RHYOLITE.

Occurrence.—The rhyolite occurs in a single area, to the west of the main area of the andesite, in the Little Harbor region. It caps the summit of the ridge at this point, and extends as a light covering to the basement rocks for several hundred feet down the southern and western slopes, the underlying formations appearing here and there. At a point about midway down the western slope the rock has a roughly bedded appearance, dipping toward the west at a rather high angle. The relation of these rocks to the other igneous rocks of the island was not learned.

Macroscopic Characters.—The rhyolite varies from compact to very vesicular, and is of a light color, nearly white

or with a tinge of pink. It appears to be considerably altered. It contains scattered phenocrysts of quartz (up to 3 mm. in diameter) with smaller and more numerous crystals of biotite. The vesicles indicate flow by their pronounced compression in one plane. Some of the cavities have a smooth, lustrous surface, and appear to be regular in shape, as if due to the leaching out of phenocrysts once contained in them. The form of two or three of these cavities strongly suggested a simply twinned feldspar.

Microscopic Characters.—In thin section the open-textured facies of the rock is seen to be composed largely of a dirty brown, very vesicular ground-mass, in which occur scattered phenocrysts of quartz and biotite, besides more or less magnetite in small grains or crystals. No phenocrysts of feldspar were seen, but one cavity was found which clearly had the form of a Carlsbad twin of feldspar. This cavity had a very narrow border of some secondary product strongly stained with limonite.

The quartz is in general quite clear, and occurs in idiomorphic forms which are usually more or less corroded. Frequent cracks traverse the sections. Besides brownish patches of included glass, the quartz contains occasional small spherulites, and sections of biotite partly or wholly included. No liquid inclusions were seen.

Biotite occurs in scattered, idiomorphic sections, generally with clear boundaries. A few of the rectangular sections are somewhat frayed at the ends. The crystals range in length from .15 mm. to .7 mm. The mineral exhibits the usual strong pleochroism.

The ground-mass consists in large part of feebly polarizing feldspar microlites in a dark isotropic matrix. A few of the vesicular cavities of the slides are nearly round, the rest being elliptical in form, and occasionally drawn out at the ends. Some contain a small amount of a clear, secondary mineral, and others, nearly spherical, are completely filled with almost opaque secondary products, dirty brown to black in color.

4. Andesite.

Occurrence.—There is one main area of the andesitic rocks with several smaller occurrences. These rocks are all, both macroscopically and microscopically, identical, and undoubtedly indicate an originally continuous area, covering the larger part of the eastern division of the island.

Ascending the ridge next the ocean, to the south of Middle Ranch Cañon, this rock is first met with at an altitude of about 300 feet, where it forms a small patch extending from this point to an elevation of about 500 feet. The next area occurs at an altitude of about 1,100 feet, where the rock not only forms the summit of this part of the ridge but caps, as well, a minor ridge which extends into the adjacent cañon. The third occurrence is near the head of this cañon. Besides these more definite areas, the soil at a number of places in this region has a purplish tinge, and the general appearance points to a more extended areal distribution of the andesite. Erosion has, however, entirely removed the rock in some places, while in others it has left only the thinnest coating on the rocks beneath, or the former covering remains simply as a coloring to the soil, in places occupied by other rocks which normally weather to a yellow.

There is a small area of andesite at the extreme southeastern end of the island. Here much of the andesite contains inclusions in varying amounts, the rock in some places being well filled with this fragmental material, which is derived in large part from earlier andesitic flows.

The main area of the andesite has a general easterly and westerly trend, and extends from the shore on the north side to the lower slopes south of Little Harbor. It reaches an extreme altitude of 2,109 feet. It consists of a series of volcanic flows which present a distinct banding on the face of the cliffs northwest and southeast of Swain's Landing. These bands have a width of four or five feet and upwards. To the east of Swain's Landing they have a dip of 10°–12° toward the Landing, while on the other side they dip in the opposite direction and at an angle of about 3°. Midway

between this point and Whitley's Cove the bands are more or less irregularly flexed, though preserving a general parallelism to the shore-line.

Another small area of these rocks is found along the coast to the east of Empire Landing.

The area of andesite near the isthmus is also formed by a series of flows which show a distinct banding along the cliff on the ocean side. This banding preserves a course roughly parallel to the water-line till near Isthmus Cove, where it changes its direction, dipping at an angle of about 25° toward the point at the entrance to the cove, as shown in the section on the map. This formation reaches its greatest altitude near the southeastern end, where it is about 900 feet above sea-level. Along the northern shore-line of this area adjoining Isthmus Cove numerous faults are seen (not shown on the map), ranging in throw from a few inches to a hundred feet or more.

The most marked feature of this area is a distinct white band following the upper line of the cliff for some distance, and overlying the volcanic rocks. This is the bed of tuff and diatomaceous earth already mentioned as occurring with the volcanics here. That the andesite lies above as well as below it is plainly seen at a number of points. An especially good section showing the upper contact of the tuff is obtained in the little bay to the east of Isthmus Cove. Here the tuff is overlain by porous andesitic rocks.

The rocks along this part of the shore have been hollowed out in places by the force of the waves, forming caves, pillars, and blow-holes.

The coarse banding of the andesites along the cliff sections shows a variety of colors, the rocks weathering in dark grayish or purplish with occasional reddish tints. The soil formed by this series of rocks is always purplish in color, and is easily distinguished, even at a distance, from the soils which the other rocks of the island form, the latter being either reddish or yellowish.

Macroscopic Characters.—The freshest specimens of the andesite are black or nearly so. Though the rocks are in gen-

eral dull, some of them have an almost greasy luster. A few of the specimens, purplish in color, appear to the eye to be fresh and compact, but with a lens it may generally be seen that they are more or less altered. Though usually compact, the rocks are vesicular in places, the irregular vesicles more or less compressed in the plane of flowage. This was noticed particularly about Isthmus Cove; also in places back of Whitley's Cove. Rarely the rock is amygdaloidal, as in the neighborhood of Whitley's Cove. The rock, though usually fracturing irregularly, at times breaks into plate-like pieces a centimeter or more in thickness. These pieces may sometimes be broken into thinner plates, owing to a laminated condition of the rock. These latter sheets vary in thickness from two millimeters to several centimeters, and their surfaces are generally yellowish from decomposition products. In other cases the rocks break into irregular masses, while showing a phenomenon similar to the foregoing in a series of fine parallel lines on those fractured surfaces at right angles to the bedding. One and only one glassy specimen of the rock was obtained, from near the small bay to the east of Isthmus Cove.

Microscopic Characters.—Microscopically the rocks, with the exception of two of the specimens examined, are pyroxene-andesites. They are usually porphyritic with a hyalopilitic ground-mass. The phenocrysts consist essentially of labradorite, augite, and hypersthene. Secondary silica is usually present in greater or less amounts. This is largely opal with occasional chalcedony. The first mineral to separate from the magma was magnetite, followed by the pyroxenes, and finally by the feldspars.

The magnetite occurs either as small octahedrons or in irregular patches, and appears to be in two generations. The largest grains are about .2 mm. in diameter. These are not very numerous. The smaller grains are more abundant, and are distributed more or less evenly through the ground-mass. These have an average diameter of about .04 mm. This scattered magnetite forms one of the most marked

features of several slides which have very few phenocrysts. It amounts in one to perhaps one-third as much as the feldspars of that slide, and equals or very slightly exceeds the amount of pyroxene. The magnetite occurs as inclusions in all the other phenocrysts.

The augite is usually idiomorphic, though where not well developed as phenocrysts it occurs as minute flakes. It is very pale green, almost colorless, and without noticeable pleochroism. Its habit is prismatic and the resulting forms are generally octagonal. The crystal outlines are usually very sharp and clear, though rounded and resorbed sections are not uncommon. The cleavage, in general, is not visible except with higher powers. Cracks are common, traversing the crystal in every direction. The augites generally are remarkably clear and free from alteration products. A few of the larger sections, however, are much dulled and cracked. Twinning parallel to the orthopinacoid is common. Liquid inclusions are numerous, occasionally reaching a diameter of .02 mm. Some inclusions of magnetite also occur.

The hypersthene differs but little from the augite in general appearance, in form, habit, inclusions, or its relation to the essential minerals, and cannot always be readily distinguished from it. The former, however, is very slightly pleochroic, and all sections give parallel extinction. It has a somewhat weaker double refraction than the augite, and the interference colors of the sections are therefore in general lower, showing yellow of the first order in the majority of cases. Further, favorable sections give characteristic interference figures. Though its habit is like that of the augite, the prismatic faces occasionally are little developed, or rarely are entirely wanting. The two minerals are occasionally intergrown.

Whenever the two pyroxenes are developed as definite phenocrysts the hypersthene is always in excess of the augite. The number of the pyroxene phenocrysts in the rocks is always much smaller than that of the feldspars, the ratio being about one to four or five.

The feldspar phenocrysts occur in idiomorphic sections and are usually lath-shaped, presenting a tabular development parallel to the brachypinacoid. There is a slight tendency to the formation of ruin-like terminals. The crystal boundaries are in many cases clear and sharp, though most of them show a varying amount of resorption both on the sides and terminals of the sections, oftener the latter. Some of the feldspars clearly show a second period of growth after having been in part resorbed into the magma. Zoning is rather common. Twinning is in accordance with both albite and Carlsbad laws. Occasional cracks penetrate the sections and some of these are brought out more clearly by a staining of limonite. In sections cut approximately perpendicular to the albite lamellation the extinction angles show the species to be labradorite. As a rule the sections of the feldspar are very fresh and clear, being free from decomposition products. Inclusions are not uncommon, consisting chiefly of brownish glass with a few small and irregular pyroxenes and occasional small grains of magnetite. The glass is usually in irregular patches and is either centrally or zonally arranged. In some cases it occurs in roughly rectangular forms zonally arranged, and with their longer axis parallel to the longer axis of the crystal. The length of the sections of labradorite varies from perhaps .06 mm. to about 1.5 mm. The sections are usually quite numerous, though their number is very variable, and some of the specimens show few phenocrysts of any sort.

The phenocrysts of the various minerals generally occur as scattered crystals, but they occasionally form small aggregates. In this case, the boundaries of the feldspars yield to those of the ferromagnesian minerals with which they are in contact. This, with the occasional complete inclusion of these minerals already mentioned, shows the later development of the feldspars.

The ground-mass consists largely of feldspar microlites with a varying amount of interstitial glass. Pyroxene occurs occasionally in flakes in the ground-mass, when but little developed porphyritically. The feldspars have a low

extinction angle, most of them extinguishing parallel to their length, thus placing them in the oligoclase-andesine series. Many of them appear to be simply twinned. In length they range up to about .04 mm. In nearly all cases they show a general parallelism due to flow. The amount of glass in the ground-mass is very variable, some of the slides being almost holocrystalline. In other cases the glass and secondary silica compose nearly one-half the ground-mass. This glass is readily distinguished from the opal by its color. The latter is yellowish brown and is quite clear, while the glass is dark and usually filled with small, irresolvable dots which may be magnetite.

Glassy Facies.—The glassy facies of the andesite, found as a very small occurrence near the isthmus, differs both macroscopically and microscopically from that just described. The rock is dark, almost black, and glassy, with yellowish patches scattered over the surface, the largest seen being 13 mm. in length. Occasional kaolinized feldspars occur, either within these yellowish patches or alone, up to a length of about 2 mm. With a lens very small hexagonal crystals of biotite are seen here and there. The dark ground-mass constitutes the bulk of the rock.

Under the microscope scattered and aggregated crystals of magnetite, hypersthene, augite, biotite, and feldspar are seen here and there in a glassy matrix. Magnetite, in grains and small octahedra, occurs as inclusions in the other minerals, and scattered through the ground-mass. There is only a moderate amount of biotite in the slides. It occurs as isolated idiomorphic sections, and was seen nowhere in contact with the other minerals. No basal sections were seen. The mineral everywhere exhibits the usual strong pleochroism.

Augite occurs either alone or with hypersthene, and while generally more or less rounded, it occasionally shows good crystal boundaries. It is pale green in color and non-pleochroic. One section of the augite showing rough crystal boundaries is wholly surrounded by a somewhat rectangular

growth of hypersthene, the augite occupying a nearly central position. The vertical axes of the two minerals are similarly oriented. The augite is simply twinned, the two halves of the section showing a very slight difference of extinction. The hypersthene is much fractured and presents the appearance of a number of rods placed in parallel position, side by side and end to end. The interstices between the rod-like parts are filled with a brownish yellow isotropic substance closely resembling the opaline silica in the slides already described. This mineral also forms an intricate network in most of the feldspars, and constitutes a considerable proportion of many of the yellowish patches which are so numerous in the rock. These yellowish areas are largely aggregates of hypersthene and feldspar.

The hypersthene is prismatic in habit and occurs, in general, either alone or in aggregations together with occasional feldspars. The feldspar and hypersthene are the most abundant minerals of the slide, the former being somewhat in excess of the latter. The hypersthene has a pronounced pleochroism, $\mathfrak{c}$ being light green in color, $\mathfrak{b}$ reddish brown, and $\mathfrak{a}$ very pale reddish. The absorption formula is $\mathfrak{c}>\mathfrak{b}>\mathfrak{a}$.

In one slide two small sections of free quartz were seen occurring quite close together and showing rounded and somewhat corroded boundaries. The sections are both crossed by numerous cracks.

The feldspars are all much resorbed, and seldom show crystal boundaries. The brownish network which most of them contain is frequently central, leaving a narrow border free from inclusions.

The ground-mass, with a high power, is seen to consist of glass filled with crystallites and microlites, with here and there perlitic cracks. With a low power the crystallites and microlites appear only as dusty particles. The perlitic cracks are distributed very irregularly, some portions of the slides being entirely free from them. They are usually quite numerous near the larger aggregates of the phenocrysts, and frequently those bordering these areas are stained

yellow. Such stained cracks show, under crossed nicols, a faint polarization, as if from some radially arranged secondary product. The microlites are capillary in form, averaging .01 mm. in length, and exhibit a slight polarization. They also show a pronounced flow structure. In smaller amount are the margarites and trichites, the latter in the form of tufts and wisps, and sometimes curled at the ends. The margarites, also, are occasionally gathered into loose tufts, radiating in all directions.

Basaltic Facies.—It was stated (page 32) that the specimens examined were all pyroxene andesites, with but two exceptions. One of these was found on the minor ridge bounding the valley of Whitley's Cove on the north, not far from the contact between the basement rocks and the volcanics. The other is from the slopes to the east of Isthmus Cove. The rocks differ from those already described, in containing iddingsite.[1] The specimen from near the isthmus is dark gray in color and very much altered, but the iddingsite occurs here in good crystal forms, while in the other specimen, which is fairly fresh, the crystal boundaries show more or less resorption. As the structure of the latter rock differs considerably from that usually found in the andesites, it will be described in some detail.

The rock is purplish and compact, but passes into a black vesicular facies, apparently differing microscopically from the compact form only in the size of the component minerals and in the amount of magnetite contained. The minerals are much smaller in the vesicular portion of the specimen, and it is almost black with magnetite, in the form of grains, long, roughly bordered rods, and irregular areas. The glassy ground-mass of this portion of the rock is filled with minute black dots, doubtless magnetite. The compact portion of the specimen has very little glass, though it contains a large amount of secondary silica, chiefly in the form of opal. The rock is nearly holocrystalline, and contains

[1] See "Geology of Carmelo Bay," by Andrew C. Lawson. Bull. Dept. Geol., Univ. Cal., Vol. 1, pp. 31-36.

very fresh, lath-shaped feldspars in two generations, besides amber-colored iddingsite and pale green augite. The specific gravity is 2.770.

The opal has the usual appearance of that mineral macroscopically. On one face of the specimen there is a considerable crust of hyalite showing a distinctly botryoidal surface when viewed with a lens. It is colorless and nearly transparent, with a vitreous luster and a hardness of about 5.5. It is infusible, dissolving in soda, with effervescence, to a clear glass. It is in large part soluble in caustic potash, and in the closed tube gives water. The areas of opal in the slides are all isotropic. The sections readily take a stain after heating with concentrated hydrochloric acid, which, however, scarcely attacks the powdered mineral. The color of the opal in thin section is light brown. Cavities occur in it, occasionally lined with chalcedony.

Both generations of feldspars appear to be labradorite, and the larger ones form the most prominent feature of the slide, being rather numerous and of considerable size, ranging in length from about 2 mm. to 3.5 mm. They are allotriomorphic, and contain, as inclusions, considerable iddingsite, besides a little glass, an occasional smaller feldspar in the largest sections, and rarely augite. The small included feldspars always show more or less resorption.

The augite occurs in small grains with very irregular boundaries. These contain many cracks which give them a granular appearance. The mineral shows no alteration and contains as inclusions occasional grains of magnetite, besides partially included small feldspars. Several sections were seen with a few small feldspars wholly enclosed.

The most characteristic mineral of the rock is the iddingsite. In amount it slightly exceeds the augite, and equals about one-third of the feldspar. It varies in size from .06 mm. to nearly .4 mm. It was the second mineral to separate from the magma, preceded by the magnetite. It occurs as usually elongated grains with very irregular boundaries, frequently marked by bays due to magmatic corrosion.

Where the original form is indicated it is very similar to that of olivine. The form is best shown in the rock from near the isthmus. That rock, however, is very soft and much altered, and no satisfactory microscopic sections of the mineral were obtained, except for the determination of the outline. Several small but good crystals were made out in the rock, with a lens. As seen thus, the general form tallies with that described by Prof. Lawson.[1] The mineral here is deep brownish red in color, with a pronounced cleavage, the cleavage surfaces presenting a somewhat metallic luster. The central portion of the crystals is usually dark green. The forms which the slides present are of two types, both hexagonal, one with a pronounced cleavage, the other without a cleavage but with a distinct fibration at right angles to the direction of elongation. The cleavage subtends an angle, two measurements of which gave 131° and 133°, respectively. Referring the mineral to the same system of axes to which Prof. Lawson has referred it, $\breve{a}$ is perpendicular to the cleavage, $\bar{b}$ in the cleavage and parallel to the fibration, $\dot{c}$ in the plane of cleavage and perpendicular to $\bar{b}$.

The cleavage is well shown by a series of parallel and narrow, open seams, to which the extinction is in all cases parallel. In sections in which the cleavage is wanting the extinction is always parallel to the longer direction of the section and to the fibration. The latter sections show a fair biaxial interference figure. The mineral is therefore orthorhombic. The emergence of the acute bisectrix is perpendicular to the plane of cleavage and $\mathfrak{b}=\bar{b}$. The optical character of the mineral, as determined by means of the quartz wedge, is negative. $\mathfrak{a}$ is therefore the acute bisectrix, and $=\breve{a}$; $\mathfrak{c}=\dot{c}$.

The color of the mineral in thin section is very variable, especially in different parts of one and the same section, ranging from a golden brown to a clear though not bright yellow, with occasional dull greenish areas in or near the center. The deeper colors are usually marginal or along

[1] *Loc. cit.*

the frequent cracks, and appear to be due to limonite formed by oxidation of the contained iron. In all the attempts made, however, this color could not be leached out by acids. The deep color of the sections and strong absorption of light prevented an entirely satisfactory determination of some of the optical properties.

The pleochroism is marked in sections transverse to the cleavage, but is not so strong in sections showing no cleavage. The absorption formula is $\mathfrak{c} > \mathfrak{b} > \mathfrak{a}$. The mineral possesses a rather low mean index of refraction. In the thinner sections the iddingsite may be seen to possess a strong double refraction, though the polarization colors are usually masked by the deep color of the mineral. In sections parallel to the plane of cleavage, though the transverse fibration parallel to $\bar{b}$ is distinct, the color of the mineral conceals the fibration at right angles to this.[1]

No satisfactory material could be obtained for investigating the mineral chemically, nor was any attempt made to analyze the rock as a whole, on account of the secondary silica contained in it. One of the slides was uncovered and an attempt was made to stain the mineral. This was successful only after several trials had been made, both with concentrated and dilute acids. Dilute boiling sulphuric acid finally caused the mineral to take the stain, the results thus agreeing with those obtained by Dr. Ransome.[2]

No definite information was obtained from the Santa Catalina specimens as to the origin of this mineral. Its occurrence in a rock of this type, and possessing the form characteristic of olivine, would certainly, in the absence of any evidence to the contrary, point to the strong probability of its being a pseudomorph after that mineral. If the mineral described by Iddings[3] is the same as that under discussion—as it appears to be—it leaves little doubt on the question.

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[1] See "The Eruptive Rocks of Point Bonita," by F. Leslie Ransome. Bull. Dept. Geol., Univ. Cal., Vol. 1, No. 3, p. 91.

[2] *Loc. cit.*, p. 92.

[3] "Geology of the Eureka District, Nevada." Monongraph XX, U. S. G. S., Appendix B, pp. 388–390.

Analysis.—The following analysis was made from a particularly fresh specimen of the andesite, obtained from the ridge forming the eastern boundary of the valley back of Swain's Landing:

SiO_2	61.05
TiO_2	.09
Al_2O_3	18.30
Fe_2O_3	3.49
FeO	1.11
MnO	trace
CaO	7.75
MgO	2.59
Na_2O	4.06
K_2O	1.36
H_2O	.71
P_2O_5	trace
	100.51
Sp. gr.	2.668

5. RELATIVE AGE.

The porphyrite was nowhere found in a fresh condition, while the andesite at many points is very fresh. The pronounced difference in the amount of alteration which the two rocks have undergone would suggest that the andesite is the younger. When the feldspars of the two are compared this difference amounts to more than a mere suggestion. These feldspars are closely related chemically, and, other things being equal, those of the older rock should show a greater amount of weathering. In the fresher andesite the feldspars are remarkably free from decomposition products, while those of the porphyrite always show a greater or less degree of alteration. In none of the specimens do the feldspars compare with those of the andesite in freshness.

More positive evidence as to the relative age of the two rocks was obtained on the western slopes of the andesites, in the Little Harbor region. Here, at an elevation of about 1,200 feet, numerous inclusions of the porphyrite are found in the andesite. They are of very irregular shape, averaging two or three inches in diameter. Differential weathering

frequently causes them to stand out on the surface of the rock. These inclusions show beyond a doubt that the porphyrite is the older of the two rocks.

B. TUFF AND DIATOMACEOUS EARTH.

1. Occurrence.

This material has already been mentioned as occurring intercalated with the andesites of the isthmus region near their upper limits, and forming a single composite bed of considerable thickness. So far as known there is but this one occurrence. Though there are excellent exposures to the east of Isthmus Cove no complete section of the bed was seen, but from the several parts it is estimated to have a thickness of from one hundred to two hundred feet.

Besides this bed on the island, there is doubtless a considerable deposit of similar material just outside of Isthmus Cove, as indicated by the sounding contours. The large scale Coast Survey map of the isthmus emphasizes this, and shows, by mapping in the contours, a more or less continuous submarine ridge, extending out some distance. This ridge is marked in its course by a shoaling of the water at one point, and by two small islands. These islands are within the 200 ft. and 300 ft. contours, and are 29 feet and 66 feet in height, respectively. The nearer of the two is composed of tufaceous material, and the outer one is probably of the same, though it was not seen near at hand.

The bed of the island is not homogeneous but is composed of numerous minor beds of varying thickness and color, now of the white shale and now of reddish, yellowish, or dark grayish tufaceous material. The thickness of a given bed is seldom the same for any distance, and it frequently happens that a bed will wedge out and disappear within a few rods. One of the beds noted changes in thickness from about six feet to one foot in a little more than fifty feet. The various beds of the formation therefore occur in no fixed order, though the bulk of the deposits is always of the diatomaceous earth.

2. Tuff.

The tufaceous beds are not wholly of volcanic material, but contain more or less of the shale fragments, besides having occasionally a matrix of the shale (diatomaceous earth). They also contain fragments of the metamorphic material similar to that composing the underlying basement rocks. The rock as a whole is rather soft, and usually somewhat compact. One of the highest beds is made up of moderately fine angular material and is somewhat porous, as it has very little cementing material. Usually fragmental shaly material appears to form most of the finer portion of the rock. Some of the beds are more or less even-grained, composed wholly of moderately fine material, and containing nothing larger than half an inch in diameter. Others contain, besides this, large angular blocks, the largest attaining a length of about two and a half feet, though most of them are less than a foot and a half in length. By the weathering of the face of the cliffs many of these blocks project from the surface. In this way both the larger and smaller fragments gradually work out and fall to the base of the cliff. These blocks are composed almost wholly of very vesicular and usually much reddened, andesitic lava. A few large fragments of shale were seen in these coarser beds and a number of angular blocks of the metamorphic material, some of them a foot and a half in length. These beds, are in places fossiliferous, and it is said that large pectens have been found in them. No fossils were found by the writer, however.

3. Shale.

The shale wherever found is white or light gray in color, but it varies considerably in texture and composition. As a rule the rock is very soft and earthy, and can be easily scratched with the nail. In this condition it has a low specific gravity. The more earthy and less compact the rock, the more easily it splits into thin sheets. The lightest

separates into paper-like fragments, almost thin enough for microscopic sections. The rock is found in two other conditions, one opaline and the other calcareous, between which and this type there are all gradations. Both these less common types are hard and compact, and are quite brittle, breaking with a conchoidal fracture. The opaline variety has a hardness of about 5, and in places has a luster like that of opal. This is No. 89, described by Dr. Hinde on page 48. The calcareous rock is somewhat darker in color than the others. It effervesces quite freely with strong acids, while with dilute acids it behaves like dolomite. The gradation of this rock into the light, earthy shale is seen by testing the different specimens with acid. The different grades of the rock show different degrees of effervescence, while the most earthy specimens give apparently none. The opaline variety does not effervesce with acid. The effervescence is due in many of the specimens to minute calcareous remains, but in the darker rock it results from the calcium-magnesium carbonate which makes up the mass of the rock. All the specimens give water in the closed tube. Heated they turn black, then white, giving off bituminous odors. The specific gravity of the earthy specimens could not be determined on account of their porous character. That of the limestone is 2.69.

No fossils of any considerable size were found in these rocks. Some of the more siliceous specimens contain minute, empty molds, arranged along the bedding planes. In one of the more compact specimens two fragmentary shell casts were seen, besides a small cast of what is probably *Tellina congesta*, Conrad. Fish-scales are quite common, with their delicate markings well preserved.

Microscopic Characters.—Under the microscope the shale is seen to consist largely of isotropic material, in which are scattered angular crystal fragments. The isotropic portions of the slides appear to be, not of glass, but wholly (or nearly so) of organic remains. The crystal fragments vary in amount in different specimens, or even in different parts of a single slide, but on the whole they form but a small percentage of

the entire rock. They are largely microscopic in size, with here and there a larger fragment reaching an extreme length of about .1 mm. This fragmental material is largely of feldspar some of which shows twinning, besides an occasional dull greenish patch of chloritic material. A few quartz fragments occur, but the source of these may be the quartzite of the basement series, as several fragments were seen in one of the slides, composed of very small interlocking grains of quartz. Most of these fragmental crystals show a feeble polarization, particularly the smaller ones. In one of the slides were seen several larger fragments of andesite, somewhat altered, but still fresh enough to show the twinning of the porphyritic feldspars.

A section of the calcareous rock shows that it is apparently free from the angular fragments of the shaly specimens, while, as before, the mass of the rock appears to consist of organic remains. With crossed nicols the larger molds are seen to be filled with calcite. The ground-mass of the rock is not isotropic, but gives the delicate polarization tints of calcite. With a high power the entire rock is seen to have a microcrystalline structure, being made up of irregular grains of calcite. This structure bears no relation to the distribution of the organic material in the rock, except in the case of the Foraminifera.

Character of the Organic Remains.—A number of small fragments of the shale were forwarded by Prof. Lawson to Dr. George J. Hinde for examination. He has kindly placed his conclusions at Prof. Lawson's disposal, in the following note.

"From small samples of these rocks sent over to me by Prof. A. C. Lawson I have prepared thin microscopic sections where the material was sufficiently coherent to allow of such being made, and in the case of the very soft rocks the fine powder has been mounted just as it occurs, without washing away the finer débris. I have only aimed in the following notes at giving a general idea of the nature of the organisms of which the rocks are composed, for the task of recognizing even the genera present would prove too long

and difficult to be undertaken, and moreover, the material at hand, though sufficient to show the general character of the organisms, would not be enough for determination of particular forms.

"No. 90. This soft, white, earthy rock is essentially diatomic in character. Both in section and in powder it is seen to consist of a mass of heterogeneously mingled fragments of diatom frustules, with a small proportion of complete forms. By far the larger mass of the rock is formed by the broken up and disintegrated particles of the diatoms, and the smallest and finest portions recognizable under the microscope are clearly organic débris. *Coscinodiscus* appears to be the predominant genus. Detached sponge spicules are fairly numerous. They are principally pin-shaped and styliform; also a few simple fusiform rods occur belonging to the Monactinellid division of siliceous sponges. The Tetractinellid sponges are represented by a few fragmentary trifid spicules and globate forms. Only one or two somewhat doubtful fragments of Radiolaria were noticed, and these organisms must have been very sparsely present, for their structures are stouter and more capable of preservation than the diatoms. The silica of these organisms—diatoms and sponges—appears to be unaltered in the fossilization—it retains the same glassy aspect as in recent examples. In addition to the siliceous organisms, Foraminifera are likewise present, and they yet retain the calcareous structure of their walls, though hardly so well preserved as in the case of the siliceous fossils. A rather large form of *Textularia* is the most common of the Foraminifera. It is to these organisms that the calcareous portions of the rock are due. The rock is very finely laminated, showing a series of well marked undisturbed layers of organic remains in which are scattered some minute angular chips of minerals here and there.

"No. 118. A whitish, comparatively soft, earthy rock. Examined both in section and in powder. Very similar to the preceding in consisting nearly wholly of diatoms and diatomic débris. *Coscinodiscus* is very numerous; some

forms relatively large. Sponge spicules are also present, but I could not certainly distinguish any Radiolaria. No Foraminifera to be seen in this specimen, and there was no reaction of the rock in acid. It is not unlikely that the calcareous organisms have been leached away, for minute empty pores can be seen in transverse sections of the beds. It has a lesser proportion of angular rock chips than the preceding (No. 90).

"No. 147. Very soft, earthy white rock, readily breaking up into fine flaky laminæ. No reaction in acid. Like the preceding this is also nearly entirely a diatomic rock, but the diatoms are here of different forms, *Melosira?* and *Grammatophora* being most conspicuous. There are fair numbers of sponge spicules, usually broken; they are chiefly pin-shaped and styliform. Neither Foraminifera nor Radiolaria were recognizable in the material examined. The angular rock chips were fewer in this rock than in the previous specimens (90 and 118).

"No. 152.[1] A pale gray, hard rock—just scratches with knife—compact, flinty fracture, readily effervesces in acid. Examined in section only. It consists, like the soft rock above referred to (No. 90), mainly of diatoms and diatomic débris; the ground-mass of the rock is, as far as can be seen under the microscope, wholly of the broken up diatom frustules. Both the minute fragments and the entire forms are as unchanged as in the soft rocks. *Coscinodiscus* is abundant, also *Navicula*, *Grammatophora* and other forms. Some of the spaces between the diatom frustules have been infilled with calcite. There are a few Radiolaria present, spheroidal and discoidal forms, but their numbers are insignificant in comparison with the diatoms. Sponge spicules are apparently absent. Foraminifera are fairly common and well preserved, showing their wall structures; the most abundant is a large species of *Textularia*, probably the same form as that in No. 90. The interiors of the Foraminifera have been infilled with calcite. Angular chips hardly to be seen in the sections of this rock.

[1] No. 152 is the limestone, the analysis of which is given later, p. 50.

"No. 89. Pale gray or cream-tinted hard rock—just scratches with knife—no action in acid. The section examined showed numerous minute pores, but whether these indicated spaces where organisms had been is doubtful. No organisms could be recognized in this rock, which, nevertheless, appears to be of opalized silica. A few angular chips could be distinguished in polarized light.

"With the exception of this last specimen, the siliceous and silico-calcareous rocks of the island of Santa Catalina are remarkable for the very slight amount of alteration which the structures of the siliceous and calcareous organisms have undergone in the fossilization. Both the most delicate diatoms and the Foraminifera occur in these beds together, in nearly as well preserved condition as in deposits now forming. The beds may well be compared with recent diatomic oozes, and, as in these latter, there is a small percentage of sponge spicules, Radiolaria and Foraminifera mingled with the prevailing diatoms. The paucity of Radiolaria in the beds is a peculiar feature. Sections of these rocks show very distinctly that the entire material, down to the smallest particles, is of organic remains mostly now broken up, for the proportion of perfect forms is small compared with the large quantity of fragmental débris. The amount of the foreign angular mineral particles is insignificant."

Chemical Characters.—This note would seem to leave no room for question as to the organic origin of the shale, but that the point might be considered from all sides, a chemical determination was made of the amount of soluble silica in the most earthy and least calcareous of the specimens. About a a gram of the roughly powdered material was used, in a ten per cent. solution of potassium hydrate. For the purpose of comparison specimens of pumice and nearly pure volcanic ash were taken and subjected to the same treatment as the shale. All the material was well dried at 100° (C) before weighing and adding to the solution. The solutions were brought to boiling twice, being allowed to stand some hours in the interval, and for about a day after the second heating.

The residues were then filtered off, and the silica was precipitated in the filtrate by acidifying with hydrochloric acid, and evaporating to dryness. The weight of the silica obtained by this process was compared with the weight of the residues, and except for the shale they all tallied very closely. All lost some silica, and on the addition of ammonia after the precipitation of the silica a slight amount of alumina was precipitated in all the solutions, showing that the alumina in the rock was acted on to some extent. The same test applied to the potassium hydrate (which occasionally contains alumina) gave no precipitate. The results showed that the pumice had lost 3.2 per cent. of silica, the volcanic ash 4.2 per cent., while the shale had lost 70.3 per cent. The powdered residue from this shale was subjected to microscopic examination, and with the higher powers was found to contain a large percentage of minute crystalline fragments. Nothing could be made of the isotropic material of the residue. A considerable amount of the residue thrown into dilute acid produces momentary effervescence, showing that a part of it is calcareous, doubtless organic remains.

Origin of the Shale.—These results show that the shale is largely composed of opaline silica, and, together with the statement of Dr. Hinde, are sufficient to disprove, for this region at least, the hypothesis tentatively advanced by Prof. Lawson[1] that the Miocene shale of the coast of California is largely of volcanic origin. That this shale is a part of the same Miocene shale which is found so extensively developed along the coast, there can be little doubt, although the proof obtained is not positive. It has a similar appearance, presents the same variations, contains abundant micro-organisms (a characteristic feature of the Miocene shales), while the occurrence of fish scales adds another link to the chain of evidence, as this is another marked characteristic of the coastal shales. Further, the Miocene shale occurs at San

[1] "The Geology of Carmelo Bay," by Andrew C. Lawson. Bull. Dept. Geol., Univ. Cal., Vol. 1, pp. 24–26.

saddle was one of their camping grounds. The specimens from the earthy blocks show a free effervescence with dilute acid, and contain in places rough, free, calcite crystals, several millimeters in diameter.

The lower slopes of the andesite in the Little Harbor region, up to an altitude of six or seven hundred feet, are everywhere strewn with rolled pebbles of andesite, porphyrite, and quartzite. Near the northern border of these lower levels there are two small deposits of white, earthy material. Along the southern border, on the ridge adjoining Middle Ranch Cañon, there is a considerable deposit of sandstone and conglomerate, and a little above this on the same slope another deposit of the earthy material. All the specimens of the latter rock wherever found effervesce freely with dilute acid. A very few rough shell casts were found in one of the areas of the earthy rock. The rock powder under the microscope showed no organic remains. The bulk of the powder gives the high polarization colors of calcite. Some of the specimens contain occasional small pebbles. In the coarser deposits there are all gradations, from conglomerate, with pebbles averaging one-half an inch in diameter, to a fine-grained, yellowish, micaceous sandstone. None of these effervesce with acids. A search for fossils revealed a few indeterminable shell-casts. These deposits of sandstone and conglomerate are in general thin, though at one point they reach a thickness of about fifteen feet.

D. BRECCIA.

Beginning near the extreme southeastern point of the island, and extending along the coast to the northward, is a small area of quartzite breccia. As seen in the gulches it is, in part at least, bedded, the beds varying in the coarseness or fineness of their material. The coarser beds contain occasional large blocks two feet or more in diameter, and, rarely, reaching a length of several yards. The material composing this breccia, so far as can be made out with a lens, is wholly quartzite, except for occasional blocks and

fragments of andesite seen near the upper part of the series. The bedding of the breccia is seen on the upper part of the cliffs at the northern end of the area as a rather coarse banding, approximately parallel to the shore-line. Toward the south the banding becomes somewhat irregular and is lost to view some time before the extreme point is reached. Here the breccia is seen at the base of the cliffs, and so far as could be determined it is, in part at least, included in the porphyrite (see Plate III, fig. 1) which occurs here on the cliffs just above.

This porphyrite is a white, much weathered rock, and it is possible that it occurs here as a dike of considerable size, or as an intrusive sheet, and does not belong to the main occurrence of this rock. At any rate it is in some respects unlike the porphyrite as it usually occurs. Within the area just described the porphyrite outcrops along the shore at one other point, at least, where the rock is to all appearances like that of the main area. The breccia at the point of the island is cut by a dike of greenish porphyrite about two feet wide, which also cuts the white porphyrite mentioned above.

About midway between Pebbly Beach and the extremity of the island there is a small beach at the base of the cliffs, which is partly made up of boulders and smaller masses of a conglomerate resembling the breccia in the material of which it is composed. This has apparently fallen from the cliffs above, although no rounded material was anywhere seen in place by the writer. So far as observed, these boulders are composed of water-worn metamorphic pebbles, imbedded in a large amount of compact, greenish cement. This cement shows a marked effervescence with dilute acid, and under the microscope it is seen to be composed in large part of angular fragments of quartz and quartzite, in a thin cement which is largely calcite. Several small sections were seen, closely resembling the porphyrite in appearance, and containing porphyritic feldspars, but much altered by decomposition products.

The observations made were too limited to prove conclu-

sively the relations of the breccia to the main body of the porphyrite and to the andesite, but some of the evidence points to the probability of its being older than either.

E. BASEMENT SERIES.

In surface area the rocks of the basement series cover a little more than half the island. They consist mainly of quartzites and mica-schists, with several smaller areas of talc- and amphibole-schists and serpentine.

The occurrences of the other basement rocks within the quartzite area were not exactly mapped, and for that reason they appear on the map without definite boundaries. The actinolite areas, in particular, are more extensive than is here indicated. The main occurrences of these rocks are as indicated, but smaller areas of all of them occur elsewhere within the quartzite area. The actinolite-schists, besides their main occurrence, are found in the area of the quartzite about Middle Ranch Cañon. The areas of the basement rocks found within the porphyrite area northwest of Avalon are in part of actinolite- and talc-schists, with some serpentine. Talc-schist is also found near the center of the west end, toward the northern coast. Besides the serpentine areas mapped, a small patch was found on the ridge to the south of Middle Ranch Cañon, and another not far from the extreme northwestern point of the island. A patch of garnet amphibolite is found just to the west of the border of the andesite in the Little Harbor region.

I. QUARTZITE.

The quartzite occurs distinctly bedded, and wherever it was possible observations for dip and strike were made, though these were insufficient to warrant a statement with regard to the beds as a whole. In many places these readings give no real indication of the general dip and strike of the series, owing to local folding with minor plications, and to occasional faulting. By a comparison of the various readings made, however, the western division of the island

appears to have a synclinal structure. Whether this is true for the division to the southeast of the isthmus cannot be stated.

An excellent cliff section showing the general stratification is seen on the southern coast of the west end, where the bedding is distinctly visible for three or four miles along the shore. For the greater part of the distance the dip of the beds is quite uniform, though the minor beds and sheets observed show intricate folding and crumpling. The dip ranges from S. 15° E. to S. 45° E., at an angle varying from 15° to about 30°.

On the northern coast of this part of the island the dip, so far as observed, is northerly, and varies considerably in amount, the average lying between 25° and 50°. A characteristic section of the bedding is shown in Plate III, fig. 1, a view of the shore at the north end of the beach of Cherry Valley, the second small bay to the north of Isthmus Cove.

The quartzites are nearly everywhere intersected by numerous veins of secondary quartz, usually of small size and running in various directions. In places, however, these veins attain a width of a foot or more. At a number of points some of the veins contain a small percentage of mineral ores.

The quartzite is usually bedded in thin and more or less irregular sheets. They range from a fraction of an inch to two or three inches in thickness, averaging perhaps half an inch. These sheets are usually separated by partings of a dark earthy character, varying in thickness from the thinnest film to about a quarter of an inch. In the more thinly bedded quartzite these partings are frequently thicker than the quartzite sheets.

Macroscopic Characters.—The quartzite is occasionally milky white; usually, however, as seen with a lens, it appears colorless and glassy. Rarely it is found black, while here and there it occurs with a tinge of pink, or even considerably reddened, owing to the presence of minute garnets, either scattered through the sheet or arranged in bands

parallel to the bedding. Many of these quartzite sheets appear to be wholly free from mica, the surface of the sheet glistening from the minute quartz crystals composing the rock. Other specimens, in cross-section, appear to be of clear quartz, but when viewed in the plane of the bedding numerous minute scales of muscovite are seen scattered over the surface. In all fractured surfaces these flakes are seen to be arranged with their planes parallel to the plane of the bedding. There are all gradations between this and specimens in which the mica is the most prominent mineral.

The layers which form the partings of the quartzite beds are quite dark, varying from a dark gray to a yellowish or reddish color due to iron stain. They are finely schistose and readily flake off; are quite soft and have usually a smooth, silvery surface. Even where this silvery luster is not at first apparent it may easily be made out with a lens. The layers appear to be composed of mica or its decomposition products. Tested chemically the mineral shows the presence of a large amount of alumina, a little iron, no lime and a little magnesia, besides giving a decided flame reaction for potassium. The optical characters of the flakes could not be determined, owing to their want of transparency.

A considerable proportion of the rocks of the west end have much the appearance of gray sandstone to the unaided eye, though with a lens they are seen to be composed largely of this micaceous material, with minute lenses or grains of the quartzite scattered through it. These mica-schists occur indiscriminately with the rocks which are more properly quartzites, and occasionally lens-shaped masses of the quartzite are found in such areas. There are all gradations between these rocks in which the mica is predominant and those in which the quartz predominates.

Besides the micaceous partings of the quartzites there were found at a number of points partings of blue amphibole, having frequently a silky luster. This amphibole also occurs in larger masses in a schistose condition. The occurrences of this rock were not mapped, but they are found

particularly in the Little Harbor region, apparently confined to the neighborhood of the areas of the amphibole- and talc-schists and serpentine. It is probable that here, as elsewhere in California, these blue amphibole-schists are due to local contact metamorphism occasioned by the intrusion of basic irruptives.[1]

Microscopic Characters.—Only one slide was made of the quartzites, which, however, is doubtless typical of the purer quartzites in general. It consists almost entirely of a mosaic of clear quartz grains of irregular shape and size. Many of them are flattened in a direction parallel to the plane of schistosity, thus giving frequently very much elongated sections. Their boundaries interlock in an extremely intricate manner. Occasional pale pink garnets occur as inclusions in the quartz, averaging a little less than .1 mm. in diameter. They are for the most part rounded, though two or three present crystal boundaries. Long narrow sections of what is probably sillimanite are comparatively numerous, nearly all arranged with their longer axes parallel to the plane of schistosity or to the direction of the flattening of the quartz grains. The terminals taper more or less gradually to a point. No cross-sections were seen. The mineral is colorless and has a moderately high index of refraction, somewhat higher than that of quartz, and it may therefore be readily distinguished from the latter in ordinary light. The double refraction is considerable, giving brilliant, though somewhat mottled, polarization colors. The extinction is in all cases parallel and perpendicular to the longer axis of the mineral. In all the sections observed the longer axis is the axis of less elasticity as shown by the quartz wedge. No optical figure was obtained.

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[1] "A Contribution to the Geology of the Coast Ranges," by Andrew C. Lawson. Am. Geol., Vol. XV (June, 1895), p. 352.

"The Geology of Angel Island," by F. Leslie Ransome. Bull. Dept. Geol., Univ. Cal., Vol. 1, No 7.

2. Actinolite and Hornblende Schists.

The actinolite-schist occurs bedded, showing greater variation than the quartzite in the thickness of the beds. It also frequently exhibits plications such as occur in the quartzite. Some of these schists occur in rather thin beds, with a finely schistose structure, the slender needles of actinolite parallel to the plane of schistosity. In other cases, especially the coarser forms of the rock, it is found showing no marked schistose arrangement. The crystals in these coarser schists frequently have a length of three or four centimeters. The rocks are more or less compact, and in general are composed of columnar or acicular actinolite crystals, but always associated with a greater or less amount of other minerals. The most common mineral accompanying the actinolite is talc. This is usually in small amounts, but rarely it becomes the dominant mineral, forming a matrix in which the needles of actinolite are embedded. Chlorite occasionally occurs with the actinolite, and like the talc, this sometimes, though rarely, becomes dominant. The chlorite varies in occurrence from minute flakes to plates several centimeters in diameter. A small amount of quartz is frequently found in these schists, and occasionally both quartz and feldspar, in varying amounts, occur associated with the actinolite and hornblende.

Almost the entire area of actinolite- and hornblende-schist is composed of the former. The latter is confined to the area which contains the serpentine, occurring here with the actinolite-schist. The rocks are coarse-grained, compact, greenish black in color, and are composed of coarsely prismatic crystalline hornblende. A small amount of mica is occasionally associated with it.

3. Serpentine.

The serpentine of this same area is found on the summits of these hills of amphibole-schist. The hills are in the neighborhood of 1,000 feet in height, and the serpentine which outcrops here is two or three hundred feet in thick-

ness. It occurs stratiform, with an average dip of from 20° to 30° in a northerly direction. The rocks are very hard and compact, and in weathering present an extremely rough surface, with projecting fragments, many of which have sharp, jagged points. It is doubtless owing to this bold, irregular surface that one of these hills has received the name of Granite Peak. The surface of this rock is also irregularly pitted. The occurences are almost wholly of this facies, and little evidence was seen of internal movement, causing a slickensided appearance. The general appearance of the rock in the field is in most respects quite unlike that of the serpentine of the Potrero, San Francisco, described by Dr. Palache,[1] which is typical of much of the serpentine of the Coast Range. There are a few small patches of magnesite within the serpentine area. The hand-specimens of the serpentine vary in color from a dirty greenish white to a dark bluish green, more or less mottled with limonite. The compact specimens show an indistinctly banded structure, and have a rather uneven fracture. This surface is entirely different from the smooth and somewhat polished surface of the pale green, slickensided specimens. Traversing the surface in lines approximately parallel to the banding are occasional fine veins and threads of chrysotile, with their fibres at right angles to the enclosing walls, and stained here and there with iron. More numerous and finer threads cross the surface at right angles to the larger veins, and nearly all are stained with limonite. Threads of magnetite run through the rock, in no fixed direction. In some places the rocks contain many minute veins of secondary silica, running at right angles to the banding. Cross-sections seen on the surface show that they are filled with the silica arranged in concentric rings. No remnants of the minerals from which the serpentine was derived were seen in any of the specimens, but it doubtless consisted in large part of olivine, for the mesh-structure characteristic of the serpen-

[1] "The Lherzolite-Serpentine and Associated Rocks of the Potrero, San Francisco." Bull. Dept. Geol., Univ. Cal., Vol. 1, No. 5, pp. 161-179.

tines so derived is seen throughout the greater part of the slides.

Areas of a somewhat different facies of the serpentine occur within the talc and garnet-amphibolite area. This rock is hard, compact, occurring massive, and not stratiform. As in the serpentines just described, minute veins of silky chrysotile traverse it here and there. The rock is very dark green, and scattered through it are aggregates of a magnesian mineral, with pearly luster, whose optical properties were not investigated. Besides this mineral, there occurs in various amounts, associated with the compact serpentine, a pale green, lamellar mineral with the optical properties of bastite.

4. TALC-SCHIST.

The area in which this serpentine is found is largely of talc-schist, usually found as a soft, foliated rock, stained yellow with limonite. It has a silvery luster, and when looked at closely the talc is seen to be of a pale green color. It is quite smooth, with a greasy feel, and is easily scratched with the nail. The rock splits readily along the schistose surfaces. Near the western end of the area, back of Empire Landing, there is a soapstone quarry where is found a facies of the schist, which but little resembles the foliated form just described. This is massive, not schistose, and has a dark gray color with a tinge of green. The rock may be scratched with the nail only in places, showing that it is not wholly talc. The chief difference between this rock and the foliated schist is the presence everywhere through it of a mineral with a pronounced lamellar structure, occurring in moderately small, bladed forms, which are interlaced in all directions. This mineral appears to be the chief constituent of the rock, and at least equal to the talc in amount. It is pale green in color, with a metalloidal luster, and a hardness of about 4. Before the blowpipe it gives the characteristic reactions of serpentine. With a lens the silvery flakes of talc may be seen here and there, besides scattered grains of pyrite.

Under the microscope the rock is seen to be composed in part of an allotriomorphic aggregate of bastite, and partly of irregular areas of talc, with several small patches of magnesite. Small amounts of pyrite are scattered through the slide.

The bastite occurs in plates or somewhat lath-shaped forms, and is colorless or with the faintest tinge of green. The mineral is non-pleochroic, even in moderately thick cleavage flakes. It has a pronounced fibration parallel to the vertical axis. Its extinction is characteristic of a rhombic mineral, being in all cases parallel to this fibration. It has a low index of refraction, and gives low interference colors, much like those of feldspar. The cleavage flakes show the fibration which is observed in thin section. Rarely a needle of pyrite is seen in the fibration. Cleavage flakes give a good biaxial interference figure, and show that the plane of the optical axes is at right angles to the plane of cleavage and parallel to the fibration. The optical character of the mineral is negative, as determined both by the mica plate and quartz wedge. The bastite is everywhere altering to talc, and all stages of the process may be seen. Alteration begins along the margin and along the cleavage planes, and works inward. Occasionally the talc occurs as a pseudomorph after the bastite, giving a parallel extinction, owing to a parallel arrangement of the fibres of the talc. Usually, however, the talc occurs in patches of irregular shape, and without a definite extinction throughout an entire revolution of the stage, owing to the compensatory effect of the irregularly oriented talc fibres.

5. ORIGIN OF THE SERPENTINES.

No detailed petrographical study was made of the serpentine rocks of the island, but such as was made proves them to be variable in their microscopic structure, and therefore different in their origin. At no point was there seen any of the unaltered rock from which the serpentine was derived, so that the conclusions must be drawn from the microscopic

structure of the serpentine itself. Judging from this, the serpentines may be roughly divided into three groups according to their probable origin: (1) those derived from pyroxenites, (2) those from rocks composed largely of olivine, and (3) those from a rock in which both rhombic pyroxene and olivine were among the essential constituents. The first are now characterized by the bastite structure, the second by the mesh-structure. It is probable that the whole of the talc-schist is derived from the first form of serpentine.

6. GARNET-AMPHIBOLITE.

Along the ridge near the upper limit of the talc-schists, and within that area, are found here and there small, projecting bosses, with occasional larger areas, of garnet-amphibolite. This rock usually presents a somewhat roughened surface, more or less reddened with iron oxide. It is not compact, and readily crumbles under the hammer. The fresher material is dark or almost black in color, and appears to be composed wholly of a brownish or greenish hornblende, with roughly rounded red garnets in varying size and amount. In some places these garnets attain a diameter of about 3 mm. and form the principal feature of the rock, while in other cases the rock is composed almost entirely of a somewhat fine-grained hornblende, and an occasional minute garnet may be made out only with the aid of a lens. At a few points the rock occurs as a black, rather coarsely granular aggregate, composed entirely of hornblende, so far as can be determined with a lens.

A slide was made of the facies of the rock containing the largest garnets. There are nine of these garnets in the slide, ranging from 2 to 3 mm. in diameter. Microscopically the rock is composed of scattered, pale pink garnets in a matrix of hornblende. Here and there are small grains of rutile. The hornblende is brownish with a tinge of green, and occurs in allotriomorphic plates, with seldom a hint of crystallographic form. The boundaries are usually well marked by a limonite stain. The sections themselves are

quite fresh and free from products of decomposition. The mineral has a pronounced prismatic cleavage. It is quite strongly pleochroic, $\mathfrak{c}$ being dark, greenish brown, $\mathfrak{b}$ deep, yellowish brown, and $\mathfrak{a}$ very pale, brownish green. The absorption scheme is $\mathfrak{c} \overline{\gtrless} \mathfrak{b} > \mathfrak{a}$. Inclusions are common, and in many of the sections abundant. They are largely minute flakes of a mineral with low polarization colors, and a refractive index somewhat higher than that of the hornblende. The same mineral occurs in scattered flakes in the garnets also, and they are there seen to be colorless or nearly so. In the hornblende these flakes are in small, open areas, usually collected near the center of the including crystal. Besides these inclusions, occasional small grains of rutile are found.

The rutile, in general, through the slide, occurs as rounded and usually oblong grains, in color deep yellowish to reddish brown, varying with the tints of amber. These grains are usually found along the lines which mark the boundaries between the hornblendes, and generally several together occur along the same line. They have an extremely high index of refraction, and on account of the consequent diffusion of light the extinctions are not sharp and clear. The direction of extinction in the grains which are distinctly elongated is parallel and at right angles to the axis of elongation. The mineral shows a pronounced though not strong pleochroism, and has a strong absorption. As the grains could not be distinguished from the dark hornblende in the crushed rock, the hornblende was dissolved out by means of hydrofluoric acid, when the minute, dark grains of the rutile could be readily distinguished from the pale red fragments of garnet, neither of these being attacked by the acid. Some of these grains were then separated and tested for titanium, with favorable results.

The garnets have quite irregular boundaries, and along the margin are frequently intergrown with the hornblendes which surround them. In a number of cases minute fragments of the garnets are completely enclosed by the bordering hornblendes, while occasionally a fragment of horn-

blende is wholly surrounded by the garnet near its margin. Frequent cracks, many of them iron-stained, intersect the garnets, without definite direction. Macroscopically the garnets appear to have a zonal structure, with a narrow and somewhat clouded outer zone, a broad middle zone, seemingly of the clear pink garnet, and a slightly darker inner zone. Under the microscope this structure is seen to be due to inclusions in the garnet. With crossed nicols the sections are, as a whole, not perfectly isotropic, but transmit a faint light in all positions. This is due to a multitude of microscopic, dust-like inclusions, which fill the central portions of the garnets. With higher powers these inclusions cannot be resolved, but are seen to be of some rather brightly polarizing mineral. They do not always occur in solid areas, for portions of the space are free from them, these isotropic portions running like veins through the mass. These areas fill the greater part of the sections, but there is always a narrow, irregular band along the margin which is free from these minute inclusions, and is isotropic under crossed nicols. The darker, central areas appear to be due to a clouding, the nature of which could not be determined. Besides these minute inclusions there are others scattered through the slide, which have been mentioned in connection with the hornblende. Some of the garnets contain here and there, particularly along the isotropic borders, minute needles of a yellowish to brownish mineral, with parallel extinction and high refractive index, and giving high polarization colors. This mineral is probably rutile. A few of these needles were seen in some of the hornblendes bordering the garnets in which the inclusions are found, and some of the needles were seen extending from the one mineral into the other. There are rarely inclusions of large grains of rutile and small hornblendes.

IV. GEOMORPHOGENY.

1. SUBMARINE TOPOGRAPHY.

The submarine contours surrounding the island have been represented for depths of 200, 300, 400 and 600 feet. The discussion of the results arrived at by a study of this feature of the topography has been left till this point, as these results are so closely connected with the geological history of the island. By mapping in the deeper contours, it is seen that the general form of the island is preserved to a depth of at least 1,800 feet, and doubtless somewhat beyond this, though the indications are that the pronounced trench outside Little Harbor gradually loses its character, so that at some greater depth the outline of the entire mass may be much simpler.

In looking at the map it will be noticed that the average distance from the shore to the 200 feet contour is much less than the average distance from the 200 feet to the 400 feet contour. This is particularly marked in those parts of the island where the cliff cutting is the most rapid. By mapping in the contours on the large Coast Survey map of the isthmus these features are strikingly brought out. Here, since there is more detail, it is readily seen that the more rapid deepening of the water near the shore extends to about 250 feet, and to this level the details of the present outline are fairly well preserved. Beyond the 250 feet contour there is a broad platform with a very gentle outward slope (of about 1°) to some point beyond the 300 feet level.

Beyond the 400 feet contour the water deepens rapidly on the southern side of the island, while on the north the widely separated contours indicate a gradual slope. The pronounced difference between the two sides is well shown in the accompanying sections (figs. 5 and 6), which were chosen as most fairly representing the average character of the two sides respectively. The first is the section along a line at right angles to the outermost point north of Whitley's Cove; the other, along a line at right angles to the

shore on the opposite side of the island, at a point to the southwest of the most southern occurrence of the andesite on the map. These sections suggest the possible origin of the island as a tilted orographic block, the rapid descent on the southern side contrasting strongly with the moderate slope on the other. The contrast is similar to that of sections taken on opposite sides of San Clemente Island which is almost certainly such a block.[1] The platform mentioned

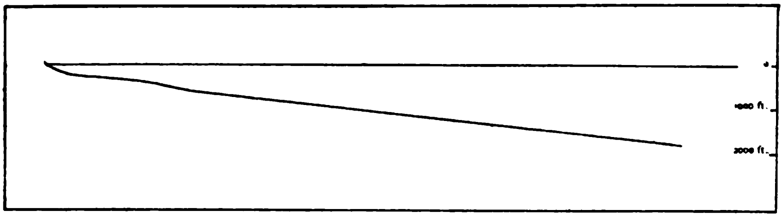


FIGURE 5—Submarine profile, north side of Santa Catalina.

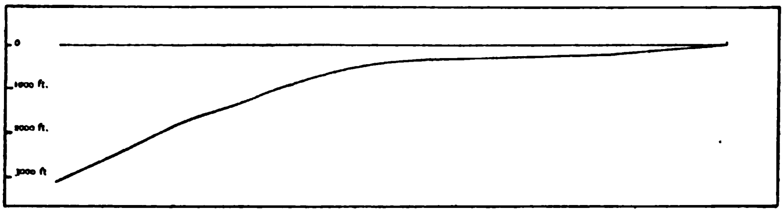


FIGURE 6—Submarine profile, south side of Santa Catalina.

as occurring above the 350 feet contour is well brought out in the section from the southern side, though the slight increase in slope above the 200 feet contour is not marked. The features make it clear that before the present sinking of the island began it stood some 350 feet higher than now. That this platform is later than the andesite is seen from the fact that it has been cut in the tufaceous deposits at the isthmus. The island stood for some time at or near that level, while rapid cutting was going on both along the cliffs on the most exposed sides, and in the softer tufaceous deposits near the isthmus, where the erosion of the harder rocks is comparatively slow. When the island had been

[1] "The Post-Pliocene Diastrophism of the Coast of Southern California," by Andrew C. Lawson. Bull. Dept. Geol., Univ. Cal., Vol. 1, No. 4, p. 129.

reduced to the form approximately shown by the 200 feet contour the present sinking began. This is shown not only by the increase of the submarine slope, but also in the isthmus chart, by the preservation of the main features of the present drainage system, showing that the recent stream-valley flooding took place at that level. The information on this point obtained from this latter source, however, is reliable only within certain limits, as a rapid, partial or complete filling up of these sunken channels in their lower levels might easily cause an error in the interpretation of the facts. But, taken in connection with the other evidence, they may be considered as trustworthy to a certain extent at least.

2. OUTLINE OF HISTORY.

The alteration and deformation of the basement rocks of Santa Catalina probably took place before the individualization of the mass now forming the island. In the opinion of the writer, the history of Santa Catalina began with the tilting of an orographic block formed of the already altered basement rocks. This view is based on the character of the submarine contours and the slight recent tilting shown in the slope of the summits (see figs. 2 and 3, page 7). The tilting was no doubt gradual, and has continued intermittently to comparatively recent times. This is shown in connection with the figures just referred to, as it was pointed out that the angle of the slope of the crest is about 1° from the horizontal, and in the direction of tilting toward the north. No further evidence of the original crust-block is seen on the land, owing to the extensive erosion to which the mass has since been subjected.

The time of the original tilting is not known, but the crust-block must have been at that time a part of the mainland. By long continued erosion the crest of the mass was carried northward so that it occupied a position now approximately represented by the main ridge from Whitley's Cove to the west end. Following this came the irruption of the

porphyrite laccolite, possibly preceded by a further tilting of the block. This irruption led to the formation of a structural valley in the Little Harbor region, between the porphyrite area and the ridge just mentioned. This valley was subsequently enlarged and deepened by an extensive erosion which followed. At this time Catalina probably stood some two or three thousand feet higher than now. The mass then had the general form of two long ridges, the one already referred to, and another having the general trend of the porphyrite area as seen on the map, and being possibly connected with the former ridge not far from its eastern end. The drainage of the large valley just mentioned was to the west. Its remnants still exist on the island, forming the amphitheater of the Little Harbor region.

This period of erosion was followed by the eruption at intervals of andesite, which completely filled a portion of this valley and covered the adjacent ridges. The source of these outpours appears to have been local. They were accompanied by a slow settling of the land area to which this mass then belonged, and Santa Catalina became an island, probably for the first time in its history. The evidence shows that it has remained an island ever since. That it was sinking at this time is shown by the deposits of tuff intercalated with the lavas.

This submergence continued after the andesite flows had ceased, for the higher portions of the andesite were somewhat eroded before the island had reached its lowest level, as is shown by the fact that the shelly deposit near Orizaba (see page 51) lies in a saddle several hundred feet below the peaks bordering it on either side. The amount of this depression was between 1,400 and 1,600 feet below the level at which the island now stands. That it was at least as great as this is shown by this same shelly deposit, which occurs at an elevation of about 1,360 feet; and that it was not greater is shown by the base-levelled summits of the island at an elevation of from 1,400 to 1,600 feet. This took place during Miocene times, as the deposits of shale near the isthmus bear witness. This submergence may

have been sufficient to form two islands of the mass, the channel between them extending from a little to the west of the isthmus, three or four miles to the east. This is based on the fact that between these points the main ridge falls considerably below the 1,400 ft. level. It may be, however, that this decrease in altitude is a part of the local depression hereafter suggested in connection with the isthmus.

The submergence was followed by a long period of erosion, during which the then existing island (or islands) was reduced to the peneplain condition. The main body was a low and nearly level area, above which, near the center, projected the higher andesitic peaks. This area contained a bay of considerable size, occupying the Little Harbor region. The reduction of the island to a peneplain was followed by an elevation, the amount of which is approximately indicated by the 350 feet submarine contour, thus making the altitude of the peneplain, roughly, 1,850 feet. This movement was gradual, and was interrupted by at least one pause, at an elevation of 600 or 700 feet above the present sea-level. This is shown by the levelled slopes in the lower portion of the Little Harbor region, and by the sedimentary deposits found on these slopes. The island remained at its highest level long enough to carve the broad submarine bench on the most exposed side. A very slow subsidence may have taken place at this time. It was followed by the present period of comparatively rapid sinking.

This most recent period has been a short one, as is shown by the small amount of cliff cutting, which has taken place since it began, on those parts of the island most exposed to wave action. It was during the period of rapid submergence that the stream valleys of the present drainage system were flooded in their lower portions (see Plate III, fig. 1, and fig. 1, page 4). For while the broad submarine platform was being carved about the island, whatever subsidence there may have been was not too rapid for the cliff cutting easily to keep pace with it. Thus no valley drowning could take place, and no trace of buried channels or sunken

valleys (belonging to the present drainage system) is found, in general, below a depth of 250 feet.

The recent tilting of the island, which has been mentioned, appears to have occurred largely if not wholly during the island's emergence after its reduction to a peneplain. For the constancy of the depth of the more recent submarine features clearly shows that their relative attitude cannot have been appreciably altered since the time of their formation, and therefore that the tilting must have preceded this in greater part, at least. To this recent differential elevation is due, in part at least, the long, narrow channels of the southern side of the island, as contrasted with the open valleys on the north; though these are doubtless due in part, also, to the more rapid cliff cutting on the southern coast.

The present drainage system of the island was begun at the time of the last rise, after the formation of the peneplain. This peneplain has since been deeply dissected and eroded, till only the roughly levelled summits of the ridges remain to mark its former existence. Sufficient time has elapsed since the streams began their work for the gorge of Silver Cañon to be cut down through more than 1,400 feet of rock, while in the same time the broader valley back of Avalon has been excavated and its slopes minutely carved. The topography, then, is by no means young, but it has not passed its prime. The submergence and rapid cliff recession tend to preserve the youthful appearance of the island, by shortening the stream channels, thus increasing their grade and causing the streams to continue their sharp, incisive cutting. To such a cause is due the dissection of the alluvial fan back of Avalon.

The isthmus is a particularly interesting feature of the island, for the mass is nearly separated at this point. A very slight further subsidence would be sufficient to form two islands. That the isthmus once formed a watershed, which separated the two stream valleys to the north and south, there can be no doubt. These drowned valleys now form the harbors on either side, and constitute the most pronounced example of valley drowning on the island. The

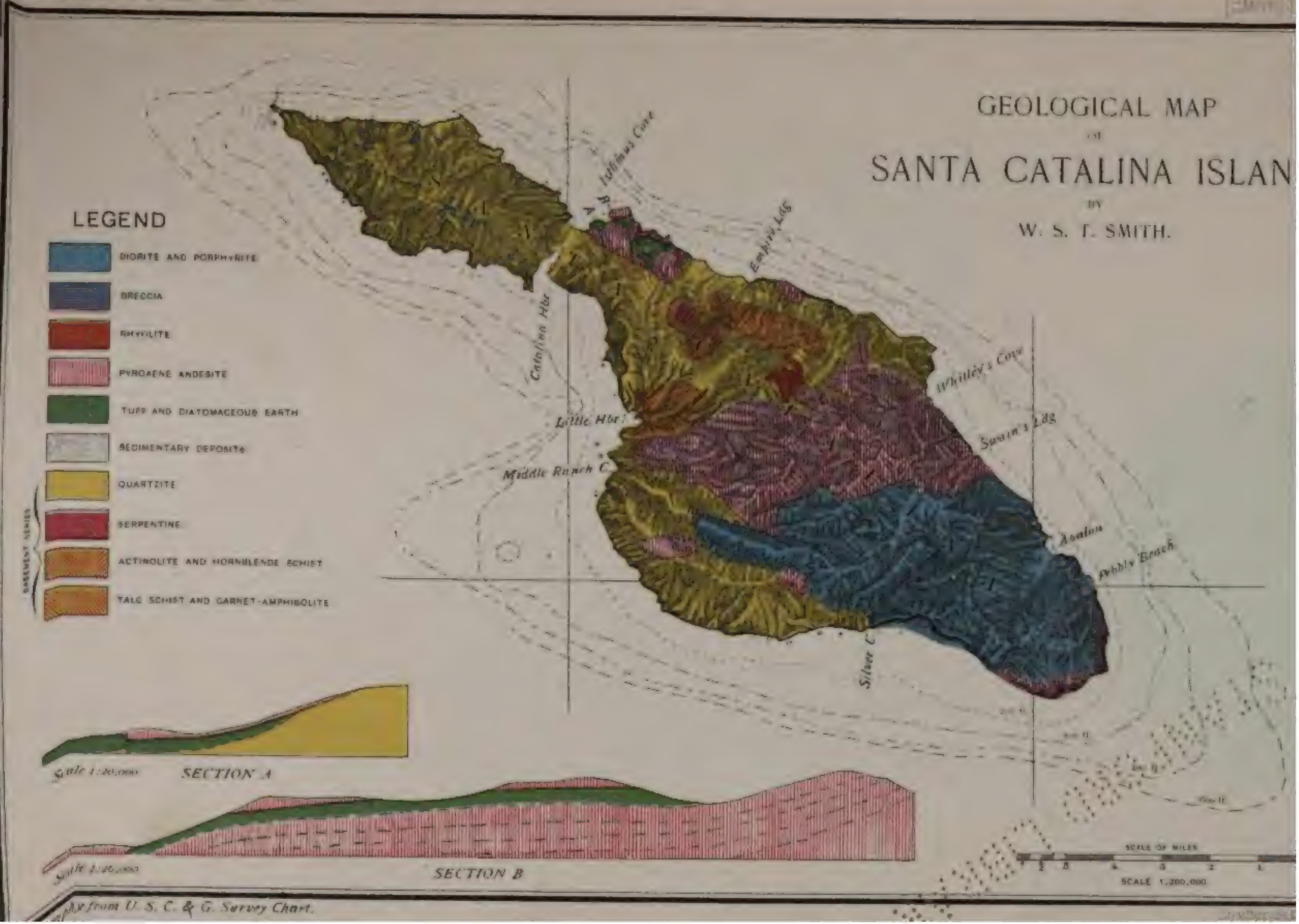
drainage into them was principally from the tributary cañons. The valleys were shallow, with only a gentle grade from the divide to their mouths, so that a comparatively slight subsidence has almost completely drowned them. The divide of the isthmus was at one time somewhat lower than at present, the pass having been filled in to a certain extent by alluvial deposits from the neighboring slopes.

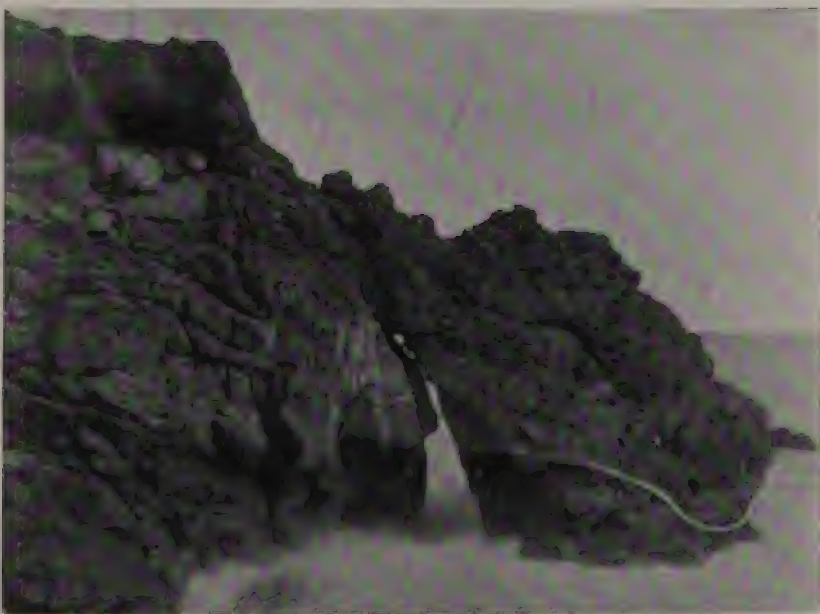
Although the harbors at the isthmus conform to the types of the present stream topography, we cannot suppose that the isthmus itself has been formed wholly by steam erosion during the present topographic cycle. The break in the continuity of the mass, which is found at this point, is too sudden and complete to be considered as due to the forces of erosion alone, in view of the fact that no such effect has been produced in any other portion of the island. The origin of the isthmus must be otherwise explained. The most reasonable hypothesis is that of a local sag at this point. This is borne out by the sudden change in the dip of the bed of tuff and diatomaceous earth, as it approaches Isthmus Cove (shown in Section A on the map). If this is due to a local depression, that depression must have occurred before the island had reached the highest point in its last rise, and after the deposition of the tuff and shale. The submarine platform at this point shows no apparent depression, so that any sag which there may have been must have taken place before the platform was carved.

In conclusion it must be said that the writer's work upon the island was, owing to limited time, necessarily incomplete, and many details remain for future investigation.

The writer wishes to express here his gratitude to Prof. Lawson for his kindness in giving advice and assistance throughout the work. Acknowledgements are also due to Dr. J. C. Merriam.

Geological Laboratory,
University of California, Oct. 1st, 1896.


GEOLOGICAL MAP
OF
SANTA CATALINA ISLAN
BY
W. S. T. SMITH.
LEGEND
DIORITE AND PORPHYRITE
BRECCIA
RHYOLITE
PYROXENE ANDESITE
TUFF AND DIATOMACEOUS EARTH
SEDIMENTARY DEPOSITS
QUARTZITE
SERPENTINE
ACTINOLITE AND HORNBLENDE SCHIST
TALC SCHIST AND GARNET-AMPHIBOLITE
BASEMENT SERIES
Isthmus Cove
Empire Ldg
Catalina Hbr
Little Hbr
Middle Ranch C.
Whitley's Cove
Swain's Ldg
Avalon
Pebbly Beach
Silver C.
Scale 1:20,000
SECTION A
Scale 1:20,000
SECTION B
SCALE OF MILES
SCALE 1:200,000
from U. S. C. & G. Survey Chart.



SOUTHEASTERN EXTREMITY OF SANTA CATALINA, SHOWING BRECCIA NEAR THE CENTER, EXTENDING INTO THE PORPHYRITE ON THE LEFT.

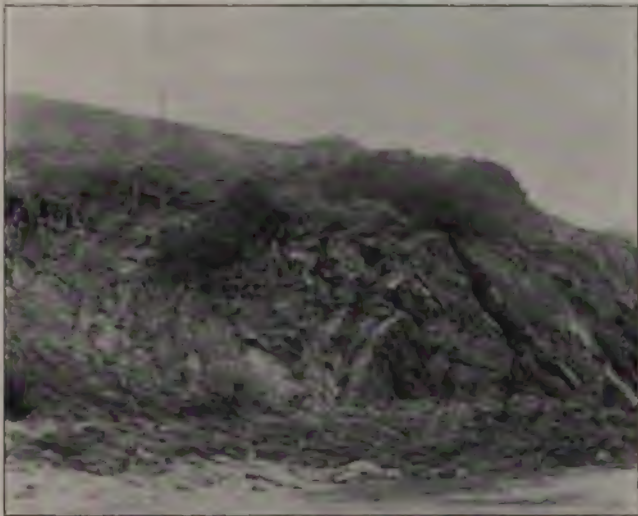


FIGURE 1—BEDDING OF BASEMENT ROCKS, CHERRY VALLEY.

FIGURE 2—AVALON HARBOR, A DROWNED VALLEY.

PROCEEDINGS

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THIRD SERIES.

GEOLOGY. VOL. I, No. 2.

The Submerged Valleys of the Coast of California, U. S. A., and of Lower California, Mexico.

BY

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THE SUBMERGED VALLEYS OF THE COAST OF CALIFORNIA, U. S. A., AND OF LOWER CALIFORNIA, MEXICO.

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I. THE EXTENT AND DIRECTION OF THE COAST NORTH OF LATITUDE 32° 32′.

THE general direction of the Pacific Coast of the United States from San Diego to the Strait of Fuca is as follows:

From San Diego, in latitude 32° 32′, longitude 117° 08′, to Point Arguello at the western entrance to the Santa Barbara Channel, in latitude 34° 34′, longitude 120° 38′, the coast runs nearly northwest by west for 225 miles; and off the northern part of this stretch lie the mountainous Santa Barbara islands. From Point Arguello to Cape Mendocino, in latitude 40° 26′, longitude 124° 22′, it runs northwest by north for 525 miles, and this stretch includes Monterey Bay, the Gulf of the Farallones, and Bodega Bay. From Cape Mendocino to Cape Flattery, in latitude 48° 23′, longitude 124° 44′, it runs north for 480 miles and is broken by the Columbia River and smaller rivers.

1. SAN DIEGO TO SANTA CRUZ.

In the region of San Diego, south and north, there are general depressions in the Coast Range of mountains; and the immediate seaboard is a terrace of 100 to 200 feet elevation, with hills rising to 1,000 feet in ten miles. The great plains of Los Angeles are thirty miles broad, and the Santa Clara River comes through a flat valley from ten to fifteen miles broad.

Abreast the Santa Barbara Channel the main shore is formed by the southern face of the high, abrupt range of Santa Ynez, which reaches 3,823 feet elevation in four and a half miles from the sea, and runs east and west. The Santa Monica is a parallel range a little to the south, ending

at Points Dumé and Mugu, but continued seaward through Anacapa, Santa Cruz, Santa Rosa, and San Miguel Islands.

North of Point Arguello are two or three valleys which lie between high ranges parallel to the Santa Ynez and which open directly upon the ocean.

Approaching San Luis Obispo Bay, where the Monte del Buchon is 1,830 feet high, the main range of the Coast mountains comes from the southeastward, reaches 4,000 feet elevation behind San Simeon Bay, and comes boldly upon the ocean a little north of Piedras Blancas, whence it runs to Carmel Bay for about 50 miles and forms the most compact and precipitous ocean barrier on the Pacific Coast. It reaches a culmination of 5,020 feet less than three miles from the sea, in latitude 36° 03′. Off this range the 2,000 fathom depth of the Pacific is only 52 miles from the shore.

At Monterey Bay there is a complete breaking down of the Coast Range for 25 miles, with the mountains receding well inland. Into this broad and deep bight heads the finest of the submerged valleys.

2. SANTA CRUZ TO CAPE MENDOCINO.

Northward of Monterey Bay, from Santa Cruz, in latitude 36° 57′, to the Golden Gate, in latitude 37° 48′, the great mountain ridge of the peninsula of San Francisco reaches 3,790 feet elevation, and offers an unbroken barrier along the ocean front for 50 miles, to the Golden Gate. This ridge is continued seaward, as shown by the submarine indications through the Farallones groups and the Cordell Bank.

The remarkable cleft in the Coast Ranges at the Golden Gate has no representative feature through the plateau of the Gulf of the Farallones. Just outside of this 100 fathom plateau commences the descent of the bottom to 2,000 fathoms, which depth is reached in 50 miles from the Southeast Farallon.

Part of the ocean barrier is continued outside of the spur of Mount Tamalpais (2,590 feet elevation), in a parallel

ridge of 1,350 feet, to the moderate ridge of Tomales Point (700 feet) and Bodega Head (241 feet).

Broad in from Bodega Bay, in latitude 38° 18′, with two esteros penetrating the tableland of 600 feet in height and the Russian River emptying into the ocean in latitude 38° 26′, there is a general break-down of the immediate Coast Range; but there are no seaward indications whatever of submerged valleys.

Northward of Bodega Head the coast mountains continue to the northwest in three or four parallel ranges or ridges, with a narrow plateau or terrace bordering the coast to and a little beyond Point Arena, in latitude 38° 57′. Thence to Cape Mendocino, in latitude 40° 26′, the coast mountains begin to rise abruptly from the ocean to 4,265 feet elevation, with no cross-cutting streams of importance, but with several moderately large streams running northwestward, parallel with the coast. There is one slight plateau projecting from the mountain flank at Point Delgada, in latitude 40° 01′. It is near the northwestern termination of this hundred miles of the Coast Ranges, where are clustered four very marked and deep submerged valleys.

3. Cape Mendocino to the Columbia River.

Northward of Cape Mendocino the Coast Ranges fall inland; they are not so high and compact as that to the southward, and are cut by many small streams fed by the heavy rains of the winter seasons. To the northward several large streams empty, and bays open upon the ocean, and miles of white sand dunes border the shore; but no indication of a submerged valley appears across the 100 fathom plateau; not even at the break-down of the range at and north of Crescent City Bay or off the Klamath River. These interrupted ranges towards the Columbia River reach 3,868 feet elevation at Mary's Peak, in latitude 44° 29′.

There is a general break-down of the ranges at the Columbia River, which discharges through a relatively low country. This great river does not come through a broad valley west

of the Cascade Mountains, but through a long gorge in the basalts, about six miles wide. This river drains a very extensive region, and it brings down immense deposits of detritus, which have formed a comparatively broad plateau of 28 miles within the 100-fathoms depth. In this plateau are evidences of a submerged valley, but further details are needed to determine its peculiarities.

4. COLUMBIA RIVER TO THE STRAIT OF FUCA.

Northward of the Columbia River the coast-line is in great measure low and backed by distant mountains, the outlying flanks of the Olympus mass.

Nearly halfway from Cape Disappointment (287 feet) these spurs gradually approach the shore until they reach Cape Flattery, with an elevation of about 1,500 feet. In this stretch of 125 miles of coast empty the waters of Willapa (formerly Shoalwater) and Gray's Bays, and two or three streams from large lakes inland: but there is no sign of a submerged valley abreast this low region. The soundings are relatively shoal for 20 miles off shore. That great inlet, the Strait of Fuca, opens upon the ocean in latitude 48° 23′–48° 31′, with the high island of Vancouver forming the north shore. The strait lies nearly east and west for eighty miles, with an average width of ten or twelve miles. It has an average depth of 100 fathoms in mid-channel, with 150 fathoms at the mouth, and a sharp turn to the southward parallel to the shore for some miles. It is the channel way for all the tidal waters of the far-stretching arms of Puget Sound on the south, and of Washington Sound and the Gulf of Georgia on the north.

II. THE ONE HUNDRED-FATHOM PLATEAU.

Off this long, bold coast thus briefly described, the waters of the Pacific reach a depth of 2,000 to 2,700 fathoms within as little as fifty miles off the mountain flanks. The descent to these profound depths is not uniform, however,

except off the face of the Sierra Santa Lucia. This deep plateau gradually shoals to the northward of Cape Mendocino, and 196 miles off the coast, between Cape Disappointment (46° 16′) and Cape Flattery (48° 24′), a depth of only 1,535 fathoms is reached. Generally there is a marginal plateau of ten miles width out to the 100 fathoms curve; and thence the descent is sharp to 500 and 1,000 fathoms. Only along a few parts of the coast does this 100-fathom plateau stretch out beyond ten miles, as follows:

The Coronados and San Diego Plateau.—This comparatively broad plateau from the southward of Los Coronados Islands to Point La Jolla reaches out as much as fifteen miles, and the 30-fathom line marks the inner edge of muddy bottom.

The Gulf of the Farallones.—The off shore soundings from Point Cypress (latitude 36° 35′) to the Farallones (latitude 37° 43′), 82 miles, show that the 100-fathom plateau stretches off shore only five miles to the north of Point Pinos, and seven miles off El Jarro, west of Santa Cruz. Thence it increases to 14 miles in width off Año Nuevo, latitude 37° 06′, and runs northwest to five miles off the Southeast Farallon, where it is 32 miles from the Golden Gate. It continues northwestward 22 miles to and beyond the Cordell Bank, in latitude 38° 01′, and again approaches the coast under Fort Ross, latitude 38° 30′, where it is only eight miles wide.

The Humboldt Plateau.—There is a narrow plateau of eight miles northward of Cape Mendocino, off the low areas of the Humboldt Bay region. It continues thence to Point St. George, latitude 41° 50′, before reaching which it is 15 miles wide in latitude 41° 30′.

The Heceta Bank.—In the latitude of the Umpquah River, 43° 40′, this plateau of 100 fathoms lies ten miles off shore; thence it trends off shore quite rapidly until in latitude 44° 03′ it is 32 miles from the comparatively low shores; thence it uniformly moves shoreward until in latitude 44° 44′. It is about 12 miles off Cascade Head, in latitude 45° 03′, and continues so for some distance northward.

From the numerous streams and low-lying valleys that

mark this stretch of coast, there are no indications of submerged valleys in this extensive plateau.

The Columbia River Plateau.—From the latitude of Tillamook Head, latitude 45° 58′, the 100-fathom plateau of the Columbia gradually sweeps out to 28 miles in breadth off the mouth of the river, and then curves eastwardly toward Shoalwater Bay, in latitude 46° 43′.

III. SOME DEEP-SEA SOUNDINGS.

Before describing the submerged valleys, it may be well to notice a few of the deep-sea soundings in order to indicate the rapid descent to the profound depths of the Pacific plateau.

Off the coast of Lower California: 2,000 fathoms off Abreojos, in latitude 26° 45′.

Off the coast from Point La Jolla to Point Pinos:

1,000	fathoms at	37	miles	W. SW.	from San Diego.
1,900	" "	128	"	W. by N.	" " "
1,674	" "	34	"	SW.	" San Miguel Island.
2,000	" "	35	"	W. by S.	" Point Conception.

At 615 miles W. by S. from Point Conception is the submarine mountain Belknap, which rises from 2,700 fathoms to 388 fathoms.

2,044	fathoms at	47	miles	SW.	from Cape San Martin.
2,000	" "	57	"	SW. by W.	from The Sur.

In other words, the depth of 2,000 fathoms is reached at 50 miles broad off the Santa Lucia range, and Cone Peak of the outer range rises to 5,020 feet in 2¾ miles from the shore; thence northwardly the 2,000-fathom line trends off the coast, and is 95 miles W. ½ N. from Point Cypress. It then approaches the coast off the Gulf of the Farallones.

Outside of the 100-fathom plateau, as we approach the Gulf of the Farallones, the depth increases very sharply to 500 fathoms within two or three miles, and reaches 800 fathoms at 18 miles SW. from Santa Cruz; thence the slope is more gradual.

2,000 fathoms at 70 miles W. SW. from Pigeon Point.

It is curious that the Vitula shoal, upon which several vessels reported only five or six fathoms, was located near where this 2,000 fathoms depth was found.

2,000 fathoms at 50 miles W. SW. from Southeast Farrallon.

1,726 fathoms at 29 miles directly W. from Southeast Farallon.

And continuing northward we have:

2,000	fathoms	at 54	miles	directly W. from Fort Ross.
2,000	"	" 71	"	" " " Point Arena.
2,000	"	" 75	"	W. SW. from Cape Mendocino.
1,700	"	" 50	"	W. from Trinidad Head (41° 03′).

A few soundings off and northwest from Cape Mendocino indicate a submarine prolongation of this range of mountains.

IV. THE SUBMERGED VALLEYS OF THE CALIFORNIA COAST.

The first discovery of a distinct valley in the submerged surface of the earth bordering the coast of California was made in 1855 by the U. S. Coast Survey. It is known as the Hueneme Submerged Valley. But as the operations of the Coast Survey did not contemplate the development of such physical characteristics, nothing further was done in subsequent surveys or studies. Later discoveries resulted merely from the hydrography necessary for navigation; but as the Santa Clara Valley opens directly upon the sea at the spreading of its fifteen mile low, flat debouchment between high mountains, it was thought that similar submerged valleys might be discovered off San Diego, San Pedro, Santa Monica, Monterey, and the Golden Gate. Certainly none were expected off Point Dumé, Carmel Bay, and the high, compact mountains south of Cape Mendocino.

All the submerged valleys so far developed lie south of

Cape Mendocino; and if attention be given to the orographical features of the coast, it will be seen that the Coast Ranges from the southward and southeastward seem to end abruptly upon the ocean front in latitude 40° 27′.

In October, 1886, the writer presented to the California Academy of Sciences some of the physical features of the submerged valleys under the high mountains immediately behind Capes Mendocino and Gorda, the more especially because the valleys lie nearly at right angles to the overhanging range. Subsequently he gathered all the data available for all the valleys, drew the contour lines to exhibit their peculiarities, and added memoranda of the character of the bottom and of the adjacent plateau. To the California series were added others partly developed by the U. S. Hydrographic Survey along the coast of Lower California. When the first short announcements of these valleys were made, they were known as "submarine valleys;" later they were designated "submerged."

The following is a condensed description of those submerged valleys, the characters of which appear in the contours thus drawn:—

1. THE SOLEDAD OR LA JOLLA VALLEY.

This valley heads southeastwardly into the slight recession of the shore-line on the north side of Point La Jolla. This point is the northern extremity of an almost isolated sandstone hill named Soledad, lying between the northern part of False Bay and La Jolla. The extent of the hill is about 3½ miles NW. and SE., and very nearly as wide E. NE. and W. NW. The ocean front is a three mile stretch of rocky, jagged shore, rising rather sharply to over 800 feet in one and one half miles. The higher part of the hill is to the W. NW. There is no very marked depression between this hill and the high land to the N. NE.; certainly nothing to indicate a submerged valley. The head of the valley is within one third of a mile of the deepest part of

the small cove, and carries 25 fathoms to within 150 yards of the three-fathom line. From its head it stretches three miles N. 40° W., to the 225-fathom curve, and then 2½ miles N. 70° W., to the 300-fathom curve, beyond which there are no immediate soundings. The valley is quite narrow out to the 200-fathom curve.

On the south side of the valley the 500-fathom line lies three miles broad off Point La Jolla, and thence the soundings deepen rapidly seaward, but to the southward the 50 fathom plateau increases in breadth to five miles off False Bay. North of the valley the 500-fathom line is barely two miles off shore and parallel therewith for 17 miles; outside this narrow plateau the water deepens rapidly to 200 fathoms. The greatest observed depth is 297 fathoms at 5⅔ miles from the beach, and about where the normal 120 fathom line would pass. Unfortunately the soundings are not numerous enough to afford much more information.

The fine dark gray sand of the bottom extends outward to about 25 fathoms. There is green mud and fine sand, with added broken shells, on the NE. and SW. slopes of the valley in 100 fathoms; at 150 fathoms, green mud alone. Approaching the head in 115 fathoms there is green mud and fine sand; and at the head in 25 fathoms hard bottom, which may be sand or rock.

The geographical position of the head of the valley at the 25-fathom curve is:

Latitude 32° 51¼′ N.; longitude 117° 16′ W.

2. The Carlsbad Submerged Valley.

One mile south of the town of Carlsbad the 50-fathom plateau is sharply indented by a broad valley 125 fathoms deep on that line. The 50-fathom curve is carried into the normal 25-fathom line; but at 200 fathoms the signs of a valley disappear. The geographical position is:

Latitude 33° 07½′ N., longitude 117° 21¼′ W.

The character of the country inside of the sea-coast plateau is irregularly rolling and reaches 2,000 feet elevation

in about 15 to 20 miles. There are three large streams coming from the San Luis Rey Mountains, with a general direction normal to the coast.

3. THE NEWPORT SUBMERGED VALLEY.

The high hills of 1,000 feet elevation westward of San Juan Capistrano, at the eastern approach to San Pedro Channel, break down almost completely in longitude 117° 53′ west, 22 miles east of San Pedro; and a large lagoon, now called Newport Bay, extends three or four miles inland, under the western flank of these hills.

There is deep water close to the shore, abreast the hills, 200 fathoms, within 3½ miles, as if a broad submerged valley were heading in toward the bay. A low, narrow, sandy peninsula extends nearly three miles in front of the bay, and at the western part of this peninsula a submerged valley reaches in close to the beach with 25 fathoms. It is well marked but not extensive, and reaches only to the 70-fathom line. West of it the broad 25-fathom plateau extends to San Pedro.

The geographical position of the head of this submerged valley is in latitude 34° 36¼′ N., longitude 117° 56′ W.

On the plateau inside of 25 fathoms, the bottom is fine gray sand, and occasionally mud; green mud and sand at 100 fathoms, and at greater depths brown mud.

A large wharf was built here under the writer's location, and this valley has protected it from storms for eight years.

4. SANTA MONICA BAY.

This broad bight or gulf is 25½ miles wide between Point Vincente at the E. SE., and Point Dumé at the W. NW., and ten miles deep at the town of Santa Monica, nearly equidistant from the two points.

The shores of this bight have marked characteristics. Point Vincente is the western rocky terminus of the isolated San Pedro Hill, 1,493 feet high, and well marked with old sea

terraces. Behind this hill for more than 20 miles to the north and east lie the great plains of Los Angeles, which drain into Santa Pedro Bay, but not into Santa Monica.

The northeastern shore of this bight for 15 miles is a sandy beach, with rolling, grass-covered sand-hills or ridges, reaching 200 feet above the sea. The northwestern shore is the western end of the Santa Monica Mountains, which reach over 3,400 feet elevation and come sharply to the coast-line, which is deeply cut by arroyos.

Three submerged valleys reach into this bight: two toward the plains, the third to the rocky head of Point Dumé, or rather to the mouth of the Cañada Zuma, 1½ miles west of Dumé.

5. THE REDONDO SUBMERGED VALLEY.

From the deepest part of Santa Monica Bay the plateau of 50 fathoms extends seaward 10 miles, but at Point Vincente it is barely a mile off the rocky shore, and 400 fathoms is then reached in two miles, and very deep water fronts the south face of San Pedro Hill.

Through this plateau the Redondo submerged valley penetrates in a general E. NE. direction and heads six miles north of Point Vincente, somewhat transverse to the direction of San Pedro Hill, and two miles north of its NW. angle. It is a deep, narrow valley, 7½ miles long inside the general 100-fathom curve, and its greatest depth, so far as sounded, is 300 fathoms. It heads square on the beach towards the Redondo Hotel. The 25-fathom curve reaches within 200 yards of the beach and the 100-fathom curve is within 1½ miles. At the 225-fathom sounding the slope is 900 feet in 2600.

Throughout the valley the bottom is soft green mud, which reaches into 25 or 30 fathoms, when fine sand and gravel are found.

There are several curious features about this submerged valley: An oil well exists at the northern part in about 75 fathoms of water; and just north of the head, inside the

beach, is a salt pond, from which salt has been extracted for many years. The surface of this pond is ten feet below the surface of the bay.

The geographical position of the head of the valley is:

Latitude 34° 50⅛′ N., longitude 118° 23½′ W.

6. THE SANTA MONICA SUBMERGED VALLEY.

This valley is markedly different from that of Vincente or Redondo, 10 miles distant to the southeastward, with the 50-fathom plateau very pronounced between them. It lies nearly parallel with the former and heads towards the middle of the beach bounding the plains of Los Angeles. Unlike the Redondo, it drops from the plateau of 50 fathoms at 5⅔ miles from the beach, with a general direction west, and a slight curve of the axis to the north. It is very much larger than the Redondo. It reaches 260 fathoms in 11⅔ miles from the beach, with the 50-fathom curve 2⅔ miles to the E. SE. and 4½ miles to the north.

The floor of the plateau is fine gray sand to 25 or 30 fathoms. In 40 fathoms, near the outermost part of the 50-fathom plateau, gravel and broken shells in one place, but green mud thence to the greatest depths.

The geographical position of the head of the 50-fathom curve is:

Latitude 34° 54⅔′ N., longitude 118° 32⅔′ W.

7. THE POINT DUMÉ SUBMERGED VALLEY.

Point Dumé at the western boundary of Santa Monica Bay is a small dome-like termination of a lower projecting plateau from the southern base of the Santa Monica Mountains, which rise to 1826 feet in 2¾ miles, and to twice that height at their culmination. It is 202 feet above the sea, and one mile to the northwest from it, along the shore, opens a short, moderately broad, treeless valley, called the Cañada Zuma. East of Point Dumé the normal 25-fathom curve is 1½ miles off the shore; to the westward it is about one mile distant;

but it stretches close under and half a mile beyond Point Dumé, only 400 yards from the low cliffs, and forms the head of the submerged valley that runs out to the SE. by S., and drops off to 238 fathoms in 1¼ miles (1,428 in 6,600 feet), and less than a mile from Dumé. The distance between the 225 fathom curves at the deepest part is less than half a mile. Unfortunately there are no soundings beyond this. In fact there are so few soundings that the characteristics of the bottom have not been given; but on both sides we find gray sand at 25 fathoms, and green mud at 125 fathoms.

The geographical position of the head of the valley is:

Latitude 35°, 00′ N.; longitude 118°, 49′ W.

8. The Point Mugu Submerged Valley.

This submerged valley lies at the eastern side of the Santa Clara Valley, near the eastern entrance to the Santa Barbara Channel. Fourteen miles west, northwest from Point Dumé, the mountain mass of Santa Monica terminates abruptly, dropping from 1,427 feet to the Laguna Mugu in less than a mile. Then the shore takes an outward, slightly convex curve for 15 or 16 miles, to San Buenaventura, with a low sand-shore immediately backed by an indurated sand that towards the west reaches 65 feet high as a steep cliff. This broad, flat, and slightly rising plain of the Santa Clara stretches many miles inland between high mountains, and through the western part of the valley runs the Santa Clara River. Where the plain meets the eastern mountain is the Laguna Mugu, with extensive marshes and a low, narrow sand beach, with a slight tidal opening as if the river may at one time have emptied here. Close upon this sand beach heads a double-armed, submerged valley, of which the details are readily given from the numerous soundings out to 500 fathoms.

The main axis of the Point Mugu Valley comes from about 475 fathoms at 11 miles SE. by S. from the head and

6½ miles from the rocky shore; runs parallel with the shore for five miles to a depth of 390 fathoms; then nearly north for four miles to 300 fathoms and curves to the NW. for three miles to 25 fathoms within a third of a mile of the receding beach. At the 275 fathom curve it gives off a branch towards the west for three miles to the 200 fathom curve, and then turns sharply to the north for three miles, ending with 25 fathoms about half a mile from the beach.

The eastern head is double and the innermost head is less than a third of a mile from the beach, and only 1¾ miles from the head of the western branch.

The fine gray sand is found out to 25 fathoms, and is mixed with mud to 50 fathoms; then green mud to 500 fathoms, except in one or two cases, when green mud and sand are given.

The geographical position of the eastern head of this valley is:

Latitude 35° $05\frac{2}{3}'$ N.; longitude 119° $06'$ W.

9. THE HUENEME SUBMERGED VALLEY.

As already mentioned, this valley heads close to the low shore of the broad Santa Clara Valley, eight miles west of Point Mugu, and nine miles east of San Buenaventura. It is therefore directly at the eastern entrance to the Santa Barbara Channel. The 25-fathom curve reaches so nearly to the beach that boats can land here when the surf along the other parts of the beach forbids an attempt at landing. The axis of the valley is nearly north and south, and is seven miles long to the 300 fathom curve. The valley is very narrow, averaging about a mile wide, and even the 25-fathom plateau on either side is sharply defined. It opens on the eastern prologation of the sharp ridge of Anacapa Island, which island, with Santa Cruz, Santa Rosa, and San Miguel is on the western prolongation of the well marked line of the Santa Monica range.

On both sides of the valley the bottom on the plateau at 15 fathoms is brown mud, a very unusual exhibition at that

small depth. In the deeper parts the bottom is dark green mud. At the mouth of the valley the 120-fathom curve stretches two or three miles into the Santa Barbara Channel.

This valley, with the two off Point Mugu, within seven miles to the eastward, is at the mouth of the Santa Clara Valley.

The 25-fathom plateau is very broad, stretching 7½ miles broad off San Buenaventura.

The geographical position of the head of the valley is:

Latitude, 34° 09′ north; longitude, 119° 13′ west.

10. THE SANTA BARBARA CHANNEL.

This channel is one of the principal features of the coast of both Lower and Upper California and is not duplicated on the Pacific Coast. It is formed by the islands stretching westward on the prolongation of the Santa Monica Mountains on the south, and the mountain barrier of the Santa Ynez Mountains, whose base forms the north shore. The islands lie nearly parallel with the main land for sixty miles, at an average distance of a little more than twenty miles. The Santa Ynez Mountains reach 3,960 feet elevation five miles behind the town of Santa Barbara, and east of the Rincon they are 2,000 feet high within a mile of the shore. The islands are mountainous and reach 980 feet elevation on Anacapa, 2,400 feet on Santa Cruz, 1,586 feet on Santa Rosa, and 861 feet on San Miguel.

The bottom of the channel reaches a depth of 341 fathoms and exhibits no abrupt contours. The western entrance shows 230 fathoms in mid-channel. Under the northern shore the bottom is soft green mud to the depths; under the island shore the mud is mixed with sand and broken shells to about 40 fathoms.

Off the northwest part of San Miguel Island the surface of the water inside 25 fathoms shows the existence of a submarine oil well.

11. THE SANTA CATALINA SUBMERGED VALLEY.

Although the great island of Santa Catalina reaches 2,110 feet elevation, and is cut near its western quarter by the "great depression" nearly to the water, yet there are some slight signs of a submerged valley on each side, pointing to this depression. Deep water surrounds the island, the 100-fathom curve lying 1½ miles from shore and being slightly closer to the northern shore than to the southern.

The island, which is 18 miles long, is traversed east and west by a great rocky ridge, whose crest keeps within 1½ miles of the north shore. On the south side of this crest-line, and on the larger part of the island, converging ridges reach generally westward to a marked indentation in the precipitous shore-line, and into this rock-bound cove the head of a submerged valley intrudes, bringing the 25-fathom curve within one third of a mile of the general curve of the shore, and the 300-fathom line within 3⅘ miles. On the southeast side of this valley the 75-fathom plateau reaches out 3⅓ miles.

At 25 fathoms the bottom is fine sand; at 40 fathoms and over, gray mud; green mud is found at 100 fathoms and more.

The geographical position of the head of the valley is:

Latitude 33° 23′ N., longitude 118° 29′ W., and its general direction seaward is west.

There is no break in the uniform bottom between Anacapa and Santa Cruz Islands.

12. THE SANTA CRUZ ISLAND SUBMERGED VALLEY.

The crest-line of the principal east and west axis of this island, which is 21 miles long, reaches an elevation of 2,150 feet. The southern parallel ridge reaches less than 1,500 feet; off this south shore the soundings drop to 600 fathoms in less than three miles.

The channel between the islands of Santa Cruz and Santa Rosa of the Santa Barbara group is nearly five miles wide,

with the depth of 25 fathoms and less over the greater part, as in the Anacapa and San Miguel passages. But into the southern entrance of this channel a very marked submerged valley intrudes, carrying the 100-fathom curve into the 25-fathom plateau, while depths of 400 fathoms are shown in two arms coming in from the E. SE.

The general direction of the valley is parallel with the southwest shore of Santa Cruz Island and is less than two miles therefrom. The general direction is W. NW. (the head) and E. SE. The plateau of 50 fathoms on the Santa Rosa side is out as far as the 400-fathom curve of the valley.

The bottom is fine gray sand out to 40 fathoms; and green mud in greater depths, except gravel and broken shells in one sounding near the 200-fathom line. The geographical position of the head of the valley in 25 fathoms is:

Latitude 34° 00′ N., longitude 119° 56′ W.

13. Northward of Cape Conception.

North of Point Arguello for some miles the mountain ranges lie parallel with the Santa Ynez range, and the streams run through the intervening valleys to the ocean. The 100-fathom plateau is narrow, yet there are no indications of any submerged valley breaking through it.

14. The Sierra Santa Lucia.

This mountain range presents the most compact and precipitous ocean barrier on this coast. It extends through one degree of latitude NW., from the cañon of San Carpóforo to Point Pinos in 36° 38′. Midway it is accentuated by the Twin Peaks that reach 5,020 feet elevation only 2¾ miles from the sea, and carries its height well to Point Sur, close behind which rises Carmel Peak to 4,417 feet. This crest-line is the outer of two parallel ranges, hardly ten miles apart; the inner reaches 6,000 feet elevation east of the

Twin Peaks. East of the inner range is the valley of the Salinas River. Off the base of this range the 100-fathom curve lies but one to three miles out, and the descent thence to 1,000 fathoms is sharp, while 2,000 fathoms is reached at 50 miles.

There are two slight indications of submerged valleys in the face of this barrier: One is faintly indicated six miles NW. of Cape San Martin, in latitude 35° 57′, heading directly into the cove under the Twin Peaks, where the 200-fathom curve reaches across the normal 100-fathom line. The second, recently developed, is more marked. It runs sharply through the 100-fathom curve, and the 25-fathom curve reaches almost to the cliffs in latitude 36° 12′, where the crest-line of the Sierra reaches 2,900 feet elevation only 1½ miles from the shore.

There is no particularly marked cañada near its head. The valley opens to the SE., parallel with the cliff-line for nearly a mile, and then bends to the S. SE. to the 200-fathom curve in less than a mile, and only $1\frac{1}{10}$ miles from the shore. The 200-fathom line is just inside the normal 100-fathom line. Near the head 94 fathoms are found one third of a mile off the cliffs.

15. THE CARMEL SUBMERGED VALLEY.

Near the northern extremity of the Santa Lucia range, and six miles south of Point Pinos, the mountains break down suddenly, and the Carmel River empties into the small cove called Carmel Bay. It is an indentation 1½ miles deep toward the east, with a breadth of three miles NW. and SE.

The submarine valley comes from the profound depth of 540 fathoms, only three miles SW. of Point Cypress, and heads to the SE., running four miles to within a mile of the shore. At 300 fathoms depth another arm heads nearly east for three miles into the southeast angle of Carmel Cove, where the 25-fathom curve is close to the shore, at the opening of a deep, narrow cañon from the mountains, which

are here 1,000 feet high. A third branch heads into the northeast angle of the bay, but the 25-fathom curve reaches in only half a mile from the shore. Between these two heads enters the Carmel River from the SE., but it is too weak and insignificant to suggest the submerged valley.

The few characteristic specimens of the bottom show green mud and sand at 100 fathoms on the south plateau; fine green mud and mica on the north plateau, and green mud, sand and mica at 475 fathoms.

Northward of Point Cypress the soundings decrease, and from Point Pinos the plateau of Monterey Bay stretches for thirty miles to the NW.

The latest soundings with the dredge show boulders under the soft muddy bottom at 480 fathoms off Point Pinos.

16. THE MONTEREY PLATEAU AND SUBMERGED VALLEY.

Monterey Bay is a great bight or gulf extending about 15 miles inside the general trend of the coast, and is about 23 miles wide.

From the general conditions of the San Francisco plateau to the northward, and the low country to the eastward, we would naturally expect the 100-fathom plateau to occupy the whole of the gulf or bay. Nevertheless, a remarkable submerged valley, similar to that of Point Hueneme, runs across this plateau and heads into a low-lying country immediately behind the 30 miles of shore-line of Monterey Bay. It reaches into the middle of this low line of beach near the mouth of the Salinas River, and the 50-fathom line is within less than half a mile of the shore.

The valley, which runs east and west, is narrow, and at seven miles from the shore the 100-fathom curves are only two miles apart and the depth 350 fathoms where the 50-fathom would be normal. It broadens, and at 11 miles has a depth of 615 fathoms. From its nothern edge a short, deep valley reaches to the northeast, but the 50-fathom curve of this arm is five miles from the shore.

The characteristic soundings adjacent to this valley are

fine soft mud, dark gray, dark yellow, and dark green, as far in as 30 fathoms of water, with occasional cases of fine dark sand, even to 150 fathoms.

Near the head of this valley empties the Salinas River from the southeast, and the Pajaro from the northeast. One or two miles inside the shore, at the head of this valley, are some very deep, fresh water lakes, but we have no certified measurements of their areas or depths. The peculiarities of the Salinas will be described in another paper.

Transpacific Cable.—The existence of this submerged valley of Monterey has been taken advantage of to propose it as the shore approach for a transpacific cable, and a line of soundings was run through it by Capt. Tanner, of the U. S. S. "Albatross," who developed a depth of 868 fathoms on the line of its axis at 16½ miles from shore. The conditions are very favorable for an undisturbed bed up to the very shore of the bay.

17. THE COAST NORTH OF MONTEREY BAY.

Northward of Monterey Bay there are several well marked breaks in the Coast Ranges, viz.:—

At the Golden Gate, at Bodega Bay, and thence to Russian River; and yet off none of these breaks is there the least sign of a submerged valley in the plateau out to 100 fathoms.

Northward of Russian River the Coast Ranges are quite compact and the elevation of the crest-line from 2,000 to 2,500 feet to Point Arena, in latitude 38° 56′.

The Walalla River breaks squarely through the outer range in latitude 38°, but there is no sign of a submerged valley off its mouth.

On the north side of Point Arena there is a receding of the shore-line for a mile or two and low country inside, but no sign of cutting through the 100-fathom plateau; thence northward the mountains increase in elevation to Cape Mendocino, where they reach 3,400 feet, with a sharp, well marked crest-line, culminating at 4,265 feet at King Peak.

Five or six miles inside this shore-line and parallel therewith the Mattole River runs to the northward and empties into the ocean two miles north of Punta Gorda; and 20 to 25 miles further inland and parallel with the shore flows the Eel River from the southeastward, through a deep valley that opens on the coast in latitude 40° 40′ just south of Humboldt Bay. The outer of these two parallel ranges rises to an elevation of 4,265 feet in latitude 40° 09′, only 2½ miles from the shore. Under the highest parts of this ocean barrier, within a distance of 20 miles along the shore, head four deep submerged valleys, between latitude 40° 06½′ and latitude 40° 23′.

The details of this part of the coast are as follows:—

18. The King Peak Submerged Valley.

A submarine ridge named the Tolo Bank runs southward from Point Delgada at Shelter Cove, in latitude 40° 01′, for ten miles or more. It has as little as seven fathoms of water upon it, and the tail of the 15-fathom curve lies five miles off shore. The depth of the marginal plateau at 100 fathoms is eight miles from shore. Just north of this bank, off Shelter Cove, there has been developed a deep, submerged valley, where it breaks through the marginal plateau and runs sharply into the immediate coast-line under the culminating point of the crest-line of the coast mountains. The head of this submerged valley is 100 fathoms deep at half a mile from the shore, and the depth of 25 fathoms almost reaches the rocks under the cliffs. The 100-fathom line of the plateau lies six miles off Point Delgada, and where this valley breaks through it the depth reaches more than 430 fathoms. The slopes of the sides of this valley are quite steep; in places the bottom drops 100 fathoms in a quarter of a mile. The general direction of the valley, which is nearly straight and parallel with the Tolo Bank, is S. SW., and its length to 450 fathoms is seven and a half miles. The bottom of the plateau is fine gray sand out to 45 fathoms, and in two or more points on the north plateau

to 75 fathoms. At greater depths the bottom is green mud, and blue mud at some soundings on the north plateau.

The mountain toward which this valley heads is King Peak, 4,265 feet high, and only two and a half miles inside the shore. The topography indicates no break in the compact rocky coast-line, although there are numerous short gulches, as in adjacent parts of the coast.

The 25-fathom head of the valley is in latitude 40° 06½′ north, longitude 124° 08′ west.

19. THE SPANISH FLAT SUBMERGED VALLEY.

This is the second of the four submerged valleys between Point Delgada and Cape Mendocino. It is only six miles northwestward of the King Peak submerged valley. We find that the 100-fathom plateau has decreased in width to a scant five miles, and the head of the valley does not reach nearer than one and three-fourths miles from the cliffs; nevertheless, it is deep and sharply defined, and has the same general direction as the King Peak; that is, northeast and southwest. Its length as exposed is nearly five miles, because the soundings reach out only to 337 fathoms. The 300-fathom curve reaches into the line of the normal 100-fathom curve and the sides have steep slopes. It heads towards the compact bold coast-line near Spanish Flat, behind which low, narrow strip the mountains rise to about 3,000 feet in two miles. The plateau has a bottom of fine gray sand to 50 fathoms, with blue and black mud on the margins of the valley; generally green mud soundings and one "rocky" in the depths.

The geographical position of the head of the valley at 25 fathoms is:

Latitude 40° 10′ north, longitude 124° 15½′ west.

20. THE PUNTA GORDA OR MATTOLE SUBMERGED VALLEY.

Punta Gorda, in latitude 40° 15½′ north, is the bold and abrupt termination of the high, narrow mountainous ridge

that comes from the southeast and separates the valley of the Mattole River from the ocean by a width of only six miles. The Mattole runs northwestward through the mountains and breaks through the high and apparently continuous mass two and a half miles northeast from Point Gorda and ten miles south of Cape Mendocino. The 100-fathom plateau reaches out six miles from the point, with indications of a drop to 600 fathoms within the next mile. At six miles from the shore a deep submerged valley of more than 520 fathoms breaks through the 100-fathom plateau.

The 25-fathom head of this valley reaches within a quarter of a mile of the shore, and about one and a quarter miles northeast of the mouth of the Mattole. Its general direction seaward is W. SW. Out to the 300-fathom depth the direction is about SW. by W. for three and one third miles, and then west to 731 fathoms. The depth of 100 fathoms in the valley is only one and a half miles from the shore, and the sides of the valley are remarkably steep. The 100-fathom curve of the valley comes close between the general 30-fathom curves of the plateau north and south, where they are only one third of a mile apart. The bottom of the 100-fathom plateau out to 50 fathoms is varied: fine gray sand, green mud, gravel, and broken shells. In the submerged valley it is green mud only in spots, the principal soundings being "gray sand" and "rocky" out to 730 fathoms—features shown in no other submerged valley.

This valley heads into the high mountain mass, but the mouth of the Mattole, one and a quarter miles to the SW., opens upon the ocean through a valley about half a mile in width, after a course of three miles from the eastward. It heads close behind the hills of Point Delgada. This stream does not carry much water in the dry season when the mouth is sometimes closed by the sand which is moved northward by the Davidson inshore eddy current.

The geographical position of the head of this submerged valley is:

Latitude 40° 18½′ north, longitude 124° 21′ west.

21. THE CAPE MENDOCINO SUBMERGED VALLEY.

This is the fourth and northernmost of the Mendocino series. The distance between Point Gorda and Cape Mendocino is 12 miles, with a very slight recession of the intervening shore-line to the eastward. The mountains come to within three miles of the ocean, with a height of 2,600 feet; at ten miles inshore they reach 3,400 feet.

We have shown that the Mattole or Punta Gorda submerged valley lies just north of that point; and yet within four miles of it to the northward enters the northenmost of this group of remarkable submerged cañons. This fourth valley lies under the southern edge of the relatively broad plateau that makes out six miles to the westward of Cape Mendocino, with only 55 fathoms. More detailed soundings have not been made. On the line of this 55 fathoms the valley has a depth of 500 fathoms and heads in nearly east to 25 fathoms about 1½ miles from the shore. It has steep sides; and in one place, on the north side, the drop is 250 fathoms or 1,500 feet in half a mile. As in the other three valleys, the bottom on the adjacent plateau has many points of green or black mud as far in as 25 fathoms. The valley itself has green mud, and yet in two places at depths of 320 fathoms broken shells were brought up with gravel. Both slopes of the valley have green mud up to 30 or 35 fathoms, when the bottom changes to fine gray sand.

The geographical position of the head of this valley in 25 fathoms is:

Latitude 40° 23′ north; longitude 124° 24′ west.

Northward of this valley the irregular and comparatively shoal bottom off Cape Mendocino, marked by Blunt's Reef and other dangers, stretches out well to the westward of the usual coast depths, and is thence spread out towards Humboldt Bay and Trinidad Head as a broad plateau inside the 100-fathom line.

The occurrence of these four characteristic submerged valleys within a lineal coast-line of 22 miles is remarkable. Cape Mendocino and the adjacent high coast is the

termination of the Coast Range of mountains coming from the south-east and forming the great ocean barrier. This range is, however, divided lengthwise by two valleys, each carrying a stream that rises in the southeast. These streams run nearly parallel with the coast-line. The western stream is the Mattole River and the eastern is the Eel River, with two principal forks. The former rises in latitude 39° 55′, and averages six miles only from the coast, and the latter rises in latitude 39° 17′, longitude 123° 20′, and averages 25 miles from the coast.

We have stated that the Mattole empties near the head of the Mattole submerged valley; the Eel River empties through a broad, beautiful, low-lying valley, 13 miles northward of Cape Mendocino, but there is no indication of a submerged valley at its debouchment.

The high terminal of this part of the Coast Ranges embraces Punta Gorda, Cape Mendocino, and False Cape, or Cape Fortunas. Signs of their extension are shown by the soundings to the northwestward, where submarine peaks rise above the general plateau of the Pacific; and it is a curious fact that all the recorded submarine earthquakes along the Pacific Coast of the United States have been felt off Cape Mendocino.

Within 50 miles northward of Eel River empty the Mad and Klamath Rivers. The great southern fork of this river is the Trinity, running parallel with the general trend of the coast south of Mendocino; but there are not the slightest indications of submerged valleys off their mouths.

Practical Bearing of these Northern Submerged Valleys.— Two problems are at once suggested by these four submarine valleys; one is eminently practical: Steam-coasting vessels bound for Humboldt Bay, when they get as far northward as Shelter Cove, haul into the shore to find soundings and then continue their course parallel to the shore. One vessel has been lost by failing to find bottom until close upon the rocky coast, and blame was attached to the captain. This steamer doubtless sounded up the axis of

the King Peak submerged valley and necessarily found no bottom with the ordinary lead line. She would run into danger between casts that were deluding. Had the existence of this valley been known at that time, the vessel would have proceeded in a different and more guarded manner.

The second bearing which these great submarine valleys have is upon the deep sea fauna which must be brought close under the shores. They carry in the colder waters coming from the north and outside of the influence of the close inshore eddy current setting to the northward.

In 1870 the writer was becalmed off Cape Mendocino for five days, in clear weather, and had a capital opportunity of determining the breadth and velocity of this Davidson eddy current, acting under the most favorable conditions, for the favorable weather had lasted through two previous days. The outer edge of the current was well marked at 15 miles off the capes and was running about one and a half miles per hour to the northward.

V. LOWER CALIFORNIA, MEXICO.

We have first described the submerged valleys of the coast of California because they are somewhat more familiar to the hydrographer and to the navigator, and more especially interesting to the geologists who are acquainted with the geology of our seaboard.

We now describe the submerged valleys of part of the Pacific Coast of Lower California, which are less known to the hydrographer and navigator, and of which the surroundings are less known to the geologist.

1. GENERAL FEATURES OF THE PENINSULA.

The principal orographical feature of the peninsula of Lower California is the great mountain chain throughout its length from latitude 23°. The mountains reach an

elevation of 10,000 feet and there are a few passes across the peninsula. Along the Pacific front the coast is much broken, rocky, and mountainous, reaching elevations of over 3,000 feet in less than five miles. A series of islands and rocks about 150 miles off shore and parallel with the peninsula would appear to indicate a submarine range of mountains, with profound depths between them, and hence to the coast.

2. THE ONE HUNDRED–FATHOM PLATEAU.

Along the whole line of the Pacific Coast of Lower California, 700 miles, the 100-fathom plateau is found in but few places. For example, from Cape Lazaro in latitude 24° 45′ to Abreojos Point in latitude 26° 45′ (130 miles NW.), under the broad indentation of this shore, the plateau of 100 fathoms stretches out 35 to 40 miles without the sign of a submerged valley through it. At the southeastern part of this plateau the prolongation of the mountainous island of Santa Margarita and Point Lazaro is clearly indicated for 75 miles to the northwest. At the northwestern part the depth drops to 2,000 fathoms only 30 miles from the plateau.

There is another 100-fathom plateau inside of Cerros Island, latitude 28° 15′, covering the whole of the Sebastian Vizcaino Bay, 60 miles wide to the 100-fathom line. Twenty miles outside of San Benito Island (close to Cerros) the depth is 1,300 fathoms. This great bay reaches in well to the southeast and is bordered by low sand dunes and great lagoons, behind which the mountains retreat far inland; yet there is no indication of any submerged valley across the 100-fathom plateau.

From the northern part of this bay to Cape San Quentin, in latitude 30° 20′, the 100-fathom plateau approaches the steep coast-line within six or seven miles.

3. THE SAN PABLO SUBMERGED VALLEY.

Point San Pablo lies in latitude 27° 13′ and is one of the prominent headlands along the west coast, projecting beyond

the general line of the coast, It is a high, rocky cliff, backed by a cluster of hills, which reach 1,800 feet elevation in two or three miles. Seven miles to the northward a deep, narrow cañon breaks upon the low shore; but there are no indications of a submerged valley off it.

The submerged valley heads close under the west side of the cliffs forming the point and is parallel with them. The 50-fathom curve reaches 1½ miles north of the point and 1¼ miles broad off the shore. From this head the valley runs to the south 2¼ miles to the 200-fathom curve, then gently curves to the southwestward to 358 fathoms in a total distance of 4¾ miles. It is comparatively narrow.

The 100-fathom plateau lies eight miles from the north shore of the point and about the same distance to the south of that point. The 358-fathom sounding lies on the normal line of the 55-fathom curve of the 100-fathom plateau.

The character of the bottom in the valley is not noted; but "rocky" and "fine sand" are given on the north plateau, and fine sand on the south.

The soundings are not carried beyond the 358 fathoms, but at 28 miles S. 20° W. from the point one depth is given at 2,155 fathoms. There are no topographical features of the coast which would suggest this submarine valley.

4. The Todos Santos Submerged Valleys.

For a distance of 30 miles (from latitude 31° 30′ to latitude 32° 00′) the normal 100-fathom line is intruded by irregular depths of 500 fathoms. One broad submerged valley, 370 to 50 fathoms deep, stretches in six or seven miles to the southeast into Soledad Bay, at 31° 35′ latitude. The submarine projection of Santo Tomas Point, which forms the southwest side of Soledad Bay, stretches out seven and one half miles, with only 50 fathoms of water; this forms the south side of the submerged valley.

A narrow submerged valley passes between Point Banda (31° 45′) and the Todos Santos Islands, and carries 200 fathoms at the gorge-like entrance. Inside the bay or gulf

of Todos Santos it expands to the 40-fathom curve. Point Banda lies 12 miles N. NW. from Point Santo Tomas.

In latitude 31° 55′ a third broad but not important submerged valley points to the east, just north of Point San Miguel, and forms part of San Miguel Bay.

It is to be noted of these three submerged valleys that the 100 and 200-fathom curves follow generally the conformation of the coast, which is quite high and precipitous, and reaches 3,347 feet elevation in two and three-fourths miles. The exception to this characteristic coast-line is in the southeastern part of the Todos Santos Bay, which is the low opening of a broad valley draining to the northwest. This low shore and valley decrease in width inland.

THE SUBMERGED VALLEY OF DESCANSO BAY.

There is clearly indicated a submarine ridge running northwest and southeast through the Coronados Islands, about seven or eight miles offshore and parallel with it. It reaches from latitude 32° 03′ to the Coronados, latitude 32° 41′. Inside of the southern point of this ridge, 7½ miles off Point Sal si Puedes, and carrying from 15 to 60 fathoms of water, there enters from the southward a broad valley, two to five miles wide, with 425 fathoms. It reaches 50 fathoms ten miles to the northward, under Point Descanso.

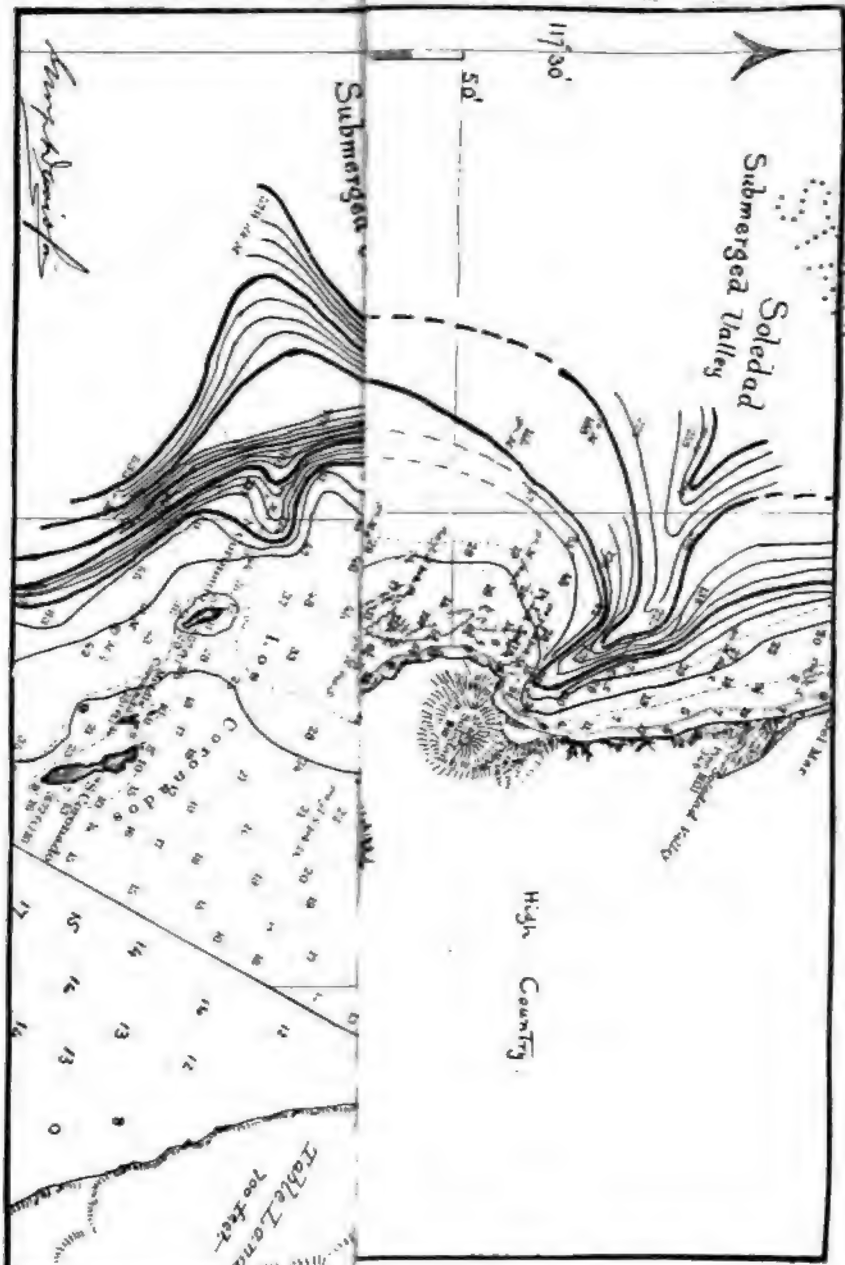
The soundings show green mud at two points north and south in this valley; land and shells on the outer ridge in 30 to 60 fathoms. Three and a half miles outside the 100 fathom plateau, in latitude 32° 18′, the depth reaches 773 fathoms.

6. THE SUBMERGED VALLEY OF LOS CORONADOS ISLANDS.

This is a deep, sharp valley penetrating the northern part of the San Diego or Coronado plateau from a depth of 622 fathoms to 50 fathoms in seven miles. Its general direction

is east, and the head is three miles north of the northern island, and seven miles from the shore, which is a low terrace under high mountains. The soundings are too few for minute illustration or description, but between two soundings of 75 fathoms, one mile apart, north and south of each other, the valley is 315 fathoms deep. This gives slopes of 1,440 feet in 3,000 feet, or about twice as steep as the heaviest grades of the streets of San Francisco.

The bottom is generally soft mud to 40 fathoms, although there is occasionally sand as deep as 600 fathoms. Gray sand and shells mark the bottom inside of 40 fathoms.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Submerged
High Country
Table Land
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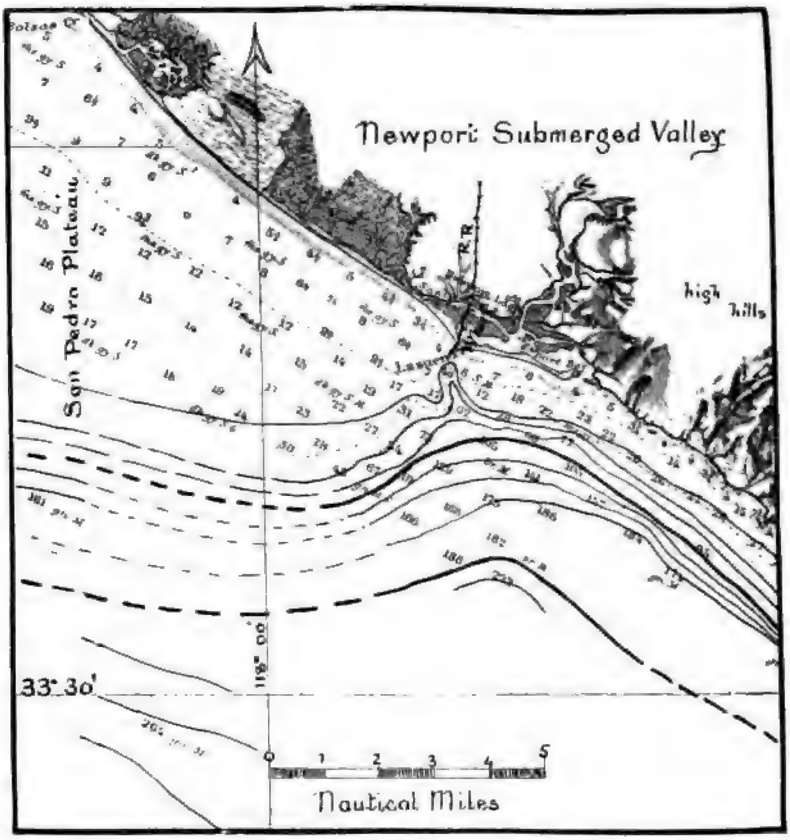
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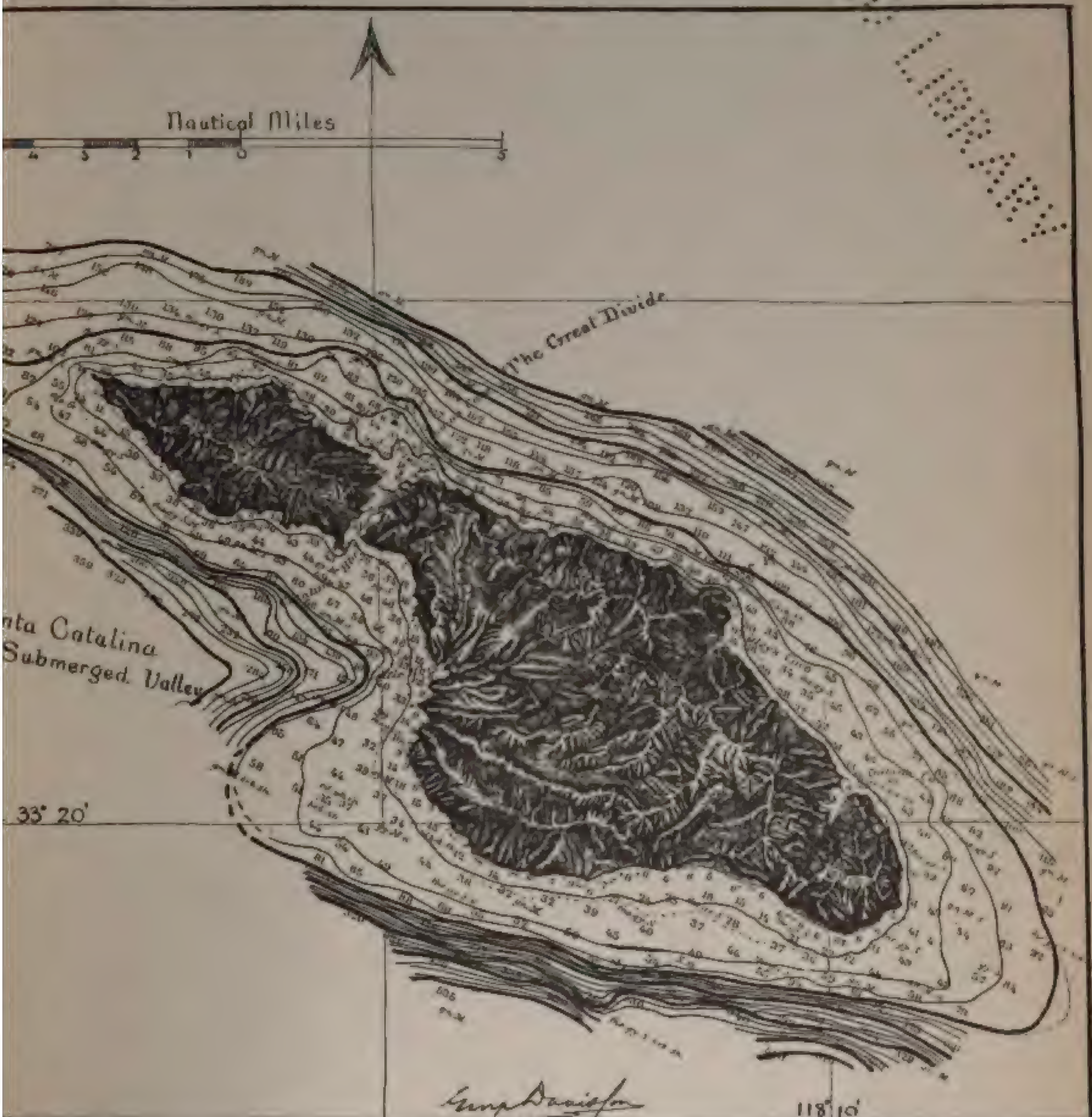
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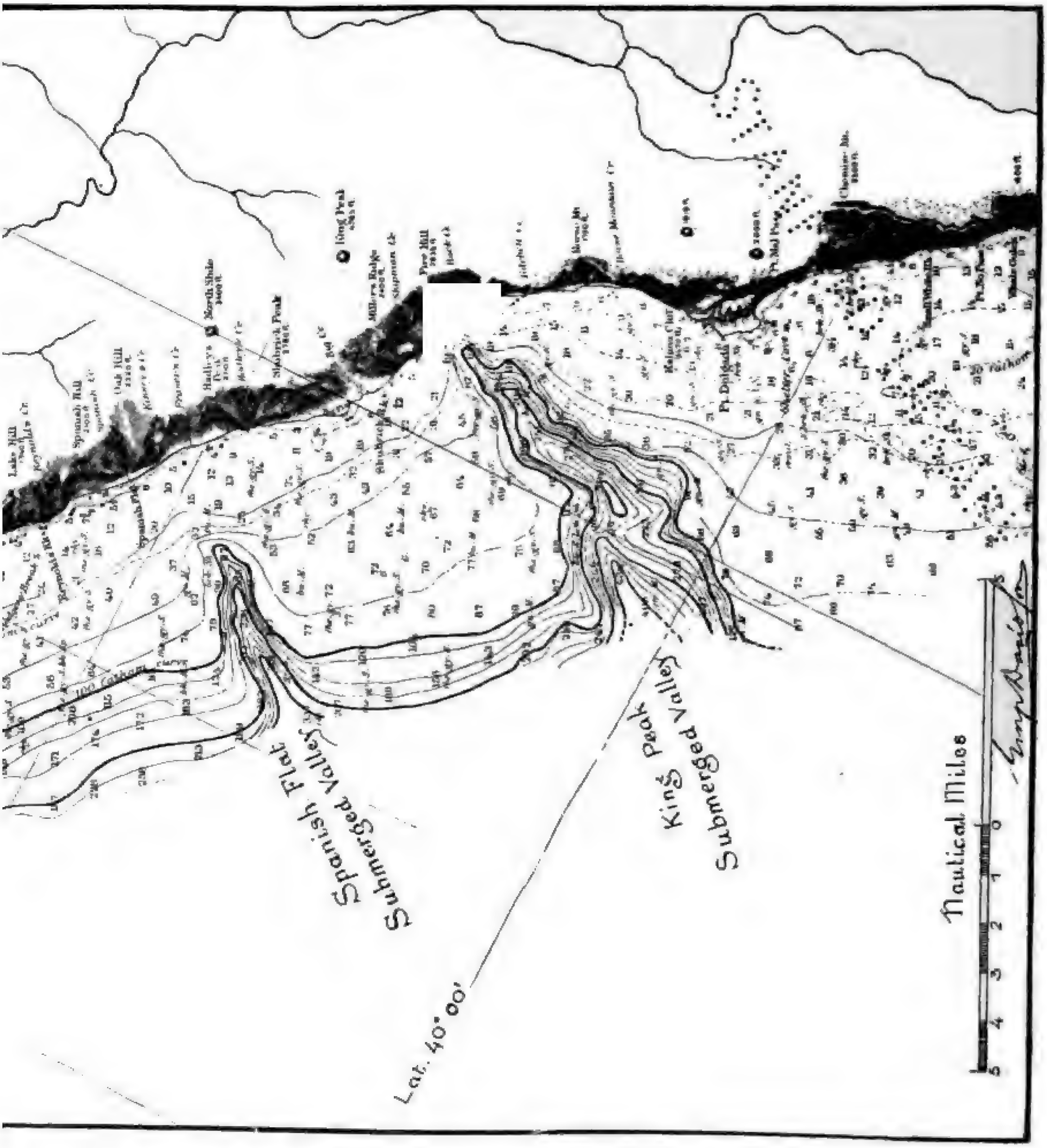
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Submerged Valley
King Peak
Submerged Valley
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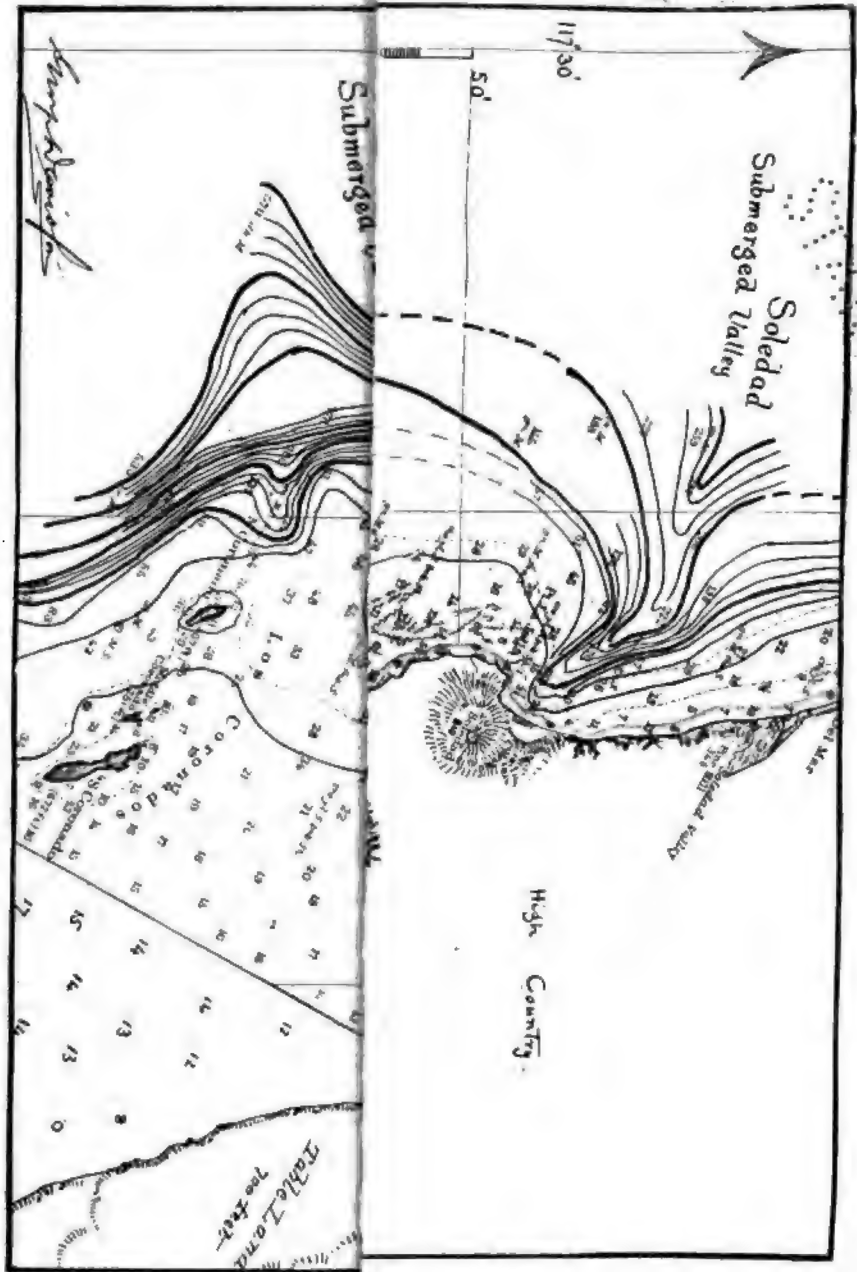
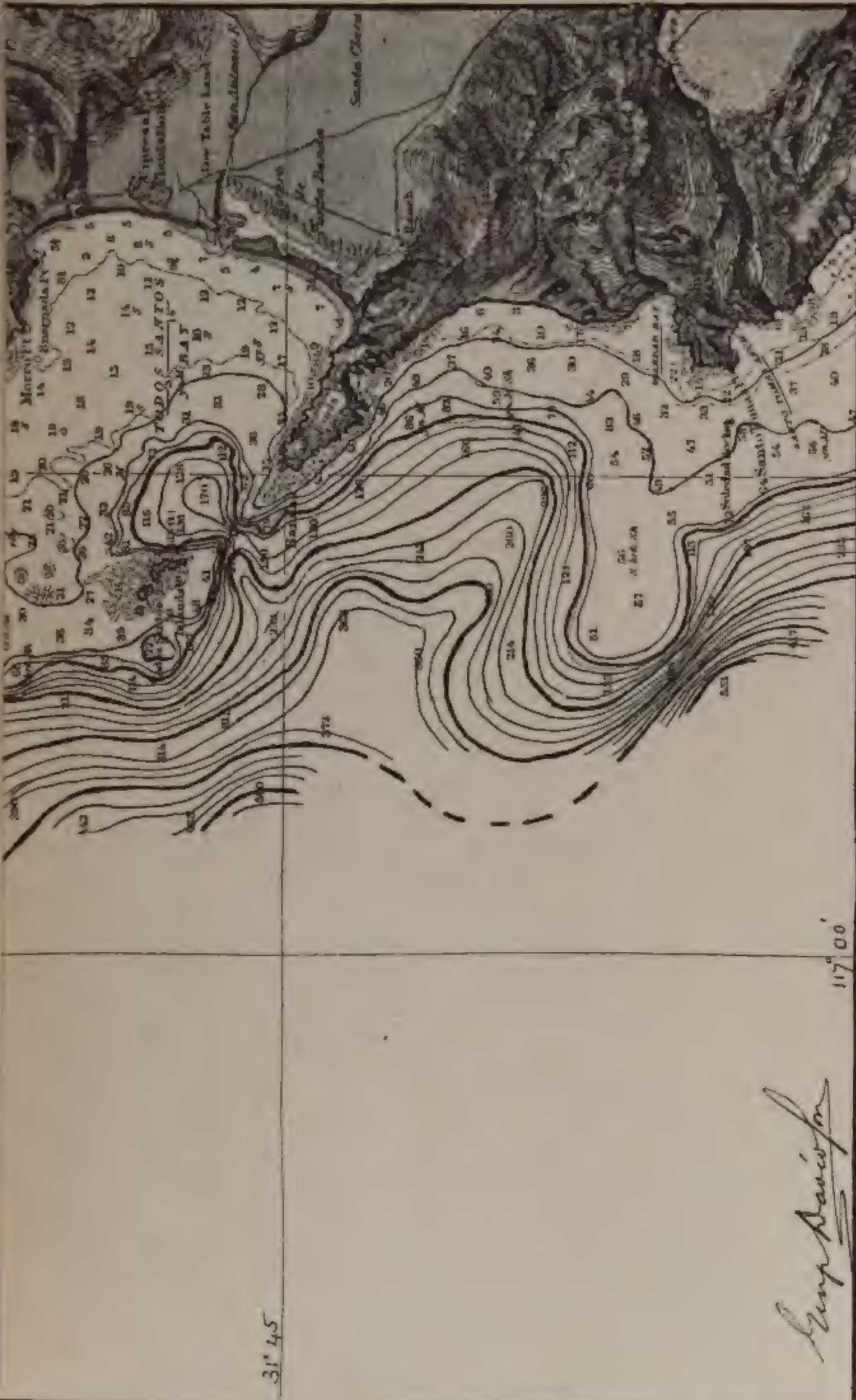

Submerged Valley
Soledad Submerged Valley
Los Coronados
High Country
Table Land 700 feet


TODOS SANTOS
31° 45'
117° 00'
Geo Davidson

PROCEEDINGS

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The Development of Glyphioceras and the Phylogeny of the Glyphioceratidæ.

BY

JAMES PERRIN SMITH.

WITH THREE PLATES.

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CONTENTS.

INTRODUCTION.

ALL modern classification is intended to be genetic, but in reality is usually not so, being based not on ontogenetic study, but rather on a comparison of supposed genetic series of adults. Much that has passed for demonstration has been in fact only conjecture. The only safe way is comparative study of ontogeny with series of adults—real phylogeny. This method of work is difficult to pursue with living forms, and still more so with fossils, although much that is good and reliable has been done with both.

The fossils that best lend themselves for this sort of work are the *Ammonoidea*, a group of cephalopods that lived from the beginning of the Devonian to the end of the Cretaceous. Being wholly extinct, the group is classified entirely by external markings, such as are capable of being preserved in

October 12, 1897.

fossils. Such marks are the sutures, the shape of the whorl, and surface ornamentation. Then, too, the ammonoids in growth envelop and protect the chambers of the earlier stages, thus preserving in a single individual a complete record of their larval history. By pulling off these outer coils the naturalist can obtain the shell in any desired stage, and can prevent the possibility of mistakes by selecting adults to start with. A study of the ontogeny of a fossil ammonoid may thus be carried on with as great accuracy as if the naturalist could hatch out and bring up the young animal in a marine laboratory.

Many authors have worked on the phylogeny of Mesozoic ammonites, and Hyatt has used especially the comparison of stages of growth of the individual with successive genera and species. But Mesozoic forms are so far from their origin that their ontogeny is long and the meaning of larval stages obscure. If we wish to learn the history of the race we must go back to the ammonoids of the Paleozoic, the goniatites. These forms, being nearer their origin, have shorter larval periods and go through fewer stages of growth; their interpretation is therefore simpler. Branco accumulated a considerable mass of exact data on the ontogeny of several goniatites, but without correlating these stages with genera. His figures are just as good and reliable as if he had done so; but since he was not looking for certain stages of growth, often the very ones we should like most to see have not been figured, due no doubt to lack of specimens. Karpinsky, in the same way, has worked out the ontogeny of *Pronorites* and *Medlicottia*, and the phylogeny of the *Prolecanitidæ*. Outside of this work the ontogeny of the goniatites is unknown, and they have been grouped together arbitrarily, often in contradiction to their true relationships. Probably so little work has been done in this line because of scarcity of specimens, especially such as can be taken apart to expose the larval stages. Paleozoic rocks have nearly everywhere been subjected to alteration and deformation, so that while species can be described from material found in them, it is rarely that one finds the inner whorls well preserved in cephalopods.

It was known to Quenstedt and L. von Buch that ammonites went through a goniatite stage in their youth; but these earlier paleontologists did not realize the importance and value of this fact, since they did not connect the idea with evolution, and hence they did not use their knowledge as a guide in classification. But we now know that the only way ever to work out the phylogeny of the ammonites is to study the development of the goniatites.

CLASSIFICATION OF GONIATITES.

Beyrich[1] first recognized the unwieldiness of the old genus *Goniatites* and attempted to subdivide it as follows: 1. *Nautilini (Anarcestes* and *Mimoceras).* 2. *Simplices (Tornoceras, Brancoceras,* and *Prionoceras).* 3. *Aequales (Sporadoceras* and *Prolecanites).* 4. *Irregulares (Beloceras).* 5. *Primordiales (Gephyroceras).* 6. *Carbonarii (Glyphioceratidæ* p. p. *Glyphioceras* and *Gastrioceras).* This classification still holds sway, except in text-books of paleontology; for the genera and families into which later writers have divided the goniatites have not generally been accepted by paleontologists.

Afterward another classification was attempted by G. and F. Sandberger,[2] which agreed substantially with that of Beyrich, except in the names given to the groups. Neither the divisions of Beyrich nor of Sandberger were intended to represent genera or families, for they mostly contain heterogeneous elements; and even at that time the old genus *Ammonites*, comprising several times as many species as the goniatites, and very much more various in form, was still considered a unit.

The first attempt to distinguish genera among the goniatites was made by Dr. E. von Mojsisovics[3] in 1882, who named *Anarcestes*, *Aphyllites*, *Pinacites*, *Pronorites*, *Prolecanites*, and *Pericyclus*, and brought them into rather fan-

[1] Beitr. Kennt. Verstein. Rhein. Uebergangsgebirge. Abhandl. Berlin Akad. Wiss., 1837.

[2] Verstein. Rhein. Schichtensystems in Nassau.

[3] Cephalopoden d. Mediterranen Trias-Provinz.

ciful relationships to his genera of Triassic ammonites. The only systematic attempt to group all goniatites into genera and families is Hyatt's classification, "Genera of Fossil Cephalopods,"[1] where all known species were grouped into genera, and these in turn in five families: *Nautilinidæ*, Lower and Middle Devonian; *Primordialidæ*, Upper Devonian; *Magnosellaridæ*, Middle and Upper Devonian; *Glyphioceratidæ*, Upper Devonian, Carboniferous, and Permian; *Prolecanitidæ*, Upper Devonian, Carboniferous, Permian, and Trias.

Steinmann[2] groups the goniatites into two families supposed to be derived from the two chief genera of the *Nautilinidæ*, *Anarcestes*, and *Mimoceras*. On page 399 of his work is given a table showing the supposed genetic connection of the various genera and also their relationship to their ammonite successors of the Mesozoic. These relationships, however, are purely speculative, and not based on ontogenetic study of the groups.

Zittel in his later work[3] recognizes only two families, *Goniatitidæ* and *Prolecanitidæ*, of which the former comprises the *Nautilinidæ*, *Primordialidæ*, *Magnosellaridæ*, and *Glyphioceratidæ*. These subdivisions may then be retained with the rank of subfamilies.

GLYPHIOCERATIDÆ *Hyatt.*

This group was established by Hyatt[4] to include a number of species from the Upper Devonian, Carboniferous, and Permian. The oldest genera are *Brancoceras* and *Prionoceras*, which began in the Upper Devonian, attained their acme in the Lower Carboniferous, and lived on into the Coal Measures. Both genera are smooth-shelled, and both have a pointed, undivided, ventral lobe, and two pairs of lateral lobes, of which the first is angular; the saddles of most species of both genera are broadly rounded,

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[1] Proc. Boston Soc. Nat. Hist., 1883, Vol. XXII.
[2] Elemente der Palæontologie, 1890.
[3] Grundzuege der Palæontologie, 1895.
[4] Proc. Boston Soc. Nat. Hist., Vol. XXII, p. 322.

although on the type of *Prionoceras*, *Goniatites belvalianus* de Koninck, the first lateral saddles are angular. The only difference between the two genera is that *Brancoceras* is compressed, high-whorled, almost discoidal, and very involute; while *Prionoceras* is broad, low-whorled, and evolute. Hyatt considers *Brancoceras* as the radicle of the *Glyphioceratidæ*, and traces the group from *Anarcestes* of the Lower Devonian, through *Tornoceras (Parodiceras)* of the Middle Devonian. He admits the near relationship between the two genera, but considers *Prionoceras* as the link between the supposed radicle *Brancoceras* and *Glyphioceras*. The genealogy of the *Glyphioceratidæ*, according to Hyatt, is as follows:

$$\text{Anarcestes}\rightarrow\text{Tornoceras}\rightarrow\text{Brancoceras}\left\{\begin{array}{l}\text{Prionoceras}\rightarrow\text{Glyphioceras}\\ \text{Münsteroceras}\rightarrow\text{Gastrioceras}\rightarrow\text{Paralegoceras}\\ \text{Dimeroceras}\rightarrow\text{Pericyclus}\end{array}\right.$$

Professor K. A. von Zittel[1] has recently merged *Prionoceras* in *Brancoceras*, not even giving subgeneric rank to the former. But even though they may be nearly related, their phylogeny justifies the separation. Both genera undoubtedly branched off about the same time from *Tornoceras* in the Upper Devonian, but *Brancoceras* is not the radicle. While it is possible, although not known, that *Münsteroceras* may go through a *Brancoceras* stage, *Prionoceras* does not, neither does *Glyphioceras*. *Prionoceras* comes directly from *Tornoceras*, and in turn gives rise to *Glyphioceras*. It seems likely, too, that some species of *Gastrioceras* descended directly from *Prionoceras* by division of the ventral lobe, while others may have come from *Münsteroceras*. In any case, whether it came off from the radicle, or through *Münsteroceras*, *Gastrioceras* is a later branch than *Glyphioceras*, not being certainly known below the Coal Measures, and having its maximum in the Upper Coal Measures; it therefore deserves to rank as an independent genus. It also seems proper to retain *Prionoceras* and *Brancoceras* with full generic rank, and *Münsteroceras* as subgenus under *Glyphioceras*.

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[1] Grundzuege der Palaeontologie, 1895, p. 398.

Genus **Glyphioceras** *Hyatt.*

This genus was established by Hyatt[1] to include Carboniferous species with semilunular whorls, usually broad and rather low; with divided ventral lobe, and a pair of angular lateral lobes; with the shell usually smooth, but in some cases with weak umbilical ribs; with periodic constrictions or varices. *Goniatites crenistria* Phillips (considered by many paleontologists as a synonym of *G. sphæricus* Martin, the type of the race of goniatites), was chosen as type of the genus. *Glyphioceras* was divided into two groups: The first with narrow umbilici, and no umbilical ribs at all, or only very weak ones; to this division belong *G. sphæricum* Martin, *G. crenistria* Phillips, and many others. The second group contains species with wider umbilici, and often with strong umbilical ribs; to this group belong *G. diadema* Goldfuss, and several others. Zittel[2] emended the genus, and included in it *Münsteroceras*, *Nomismoceras*, and *Homoceras*. Karpinsky[3] afterward attempted to show that *Glyphioceras* and *Gastrioceras* grade over into each other, and that there is no reason for retaining the two as independent genera. But just this same thing might be said of any two nearly related genera. There is certainly no difficulty in distinguishing typical members of both groups; and since *Gastrioceras* is a later branch than *Glyphioceras*, it facilitates phylogenetic study to consider them as distinct. As thus emended and restricted, *Glyphioceras* contains species from the Carboniferous, ranging from the Waverly horizon, goniatite-beds of Rockford, Indiana, the very base of the system, up into the Permian.

Little work has been done on the phylogeny of this genus, notwithstanding its importance as the chief member of the Carboniferous ammonoids and the type of the whole race of goniatites. The first observations were made by Hyatt[4],

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[1] Proc. Boston Soc. Nat. Hist., Vol. XXII, p. 328.

[2] Handbuch der Palæontologie, Abtheil I, Band II, p. 420.

[3] Mém. Acad. Sci. St. Petersbourg, Tome XXXVII, No. 2. Ammoneen der Artinsk-Stufe, p. 46.

[4] Bull. Mus. Compar. Zoöl., Vol. III, 1872, No. 5, Pl. II, figs. 3 and 4.

who figured a larva of *Glyphioceras diadema* Goldfuss, consisting of the protoconch with two-thirds of the first whorl attached. Branco[1] afterward figured the protoconch and two larval stages of *G. diadema* at diameters of 0.66 mm., and 0.90 mm. respectively. He noted, too, that on this species the ventral lobe became divided at a diameter of six millimetres, although his figure I, on Plate IV, shows the ventral lobe broadening and preparing for division at diameter of 2.25 mm. But the consecutive larval stages were not figured and described, nor were they compared with known genera, although that does not lessen the value of his data.

Hyatt in his "Genera of Fossil Cephalopods" often compares the larvæ of this group of goniatites to their ancestral genera, but as the paper is not accompanied by illustrations and systematic descriptions of stages of growth of the species cited, it is not easy to follow the correlations. It was therefore desirable that some typical species of *Glyphioceras* should be studied in detail from the protoconch upwards, and material suitable for this was found in *G. incisum* Hyatt, from the Fayetteville shale, Warsaw division of the Lower Carboniferous, at Moorefield, Independence County, Arkansas.

Glyphioceras incisum *Hyatt.*

PLATES XIII-XV.

Glyphioceras incisum HYATT, Geol. Surv. Texas, Fourth An. Report, p. 471, Pl. XLVII, figs. 44-48.

The form is globose, broad, low-whorled, with semilunular cross-section, and very involute; in the adult the umbilicus is closed so that the inner whorls are concealed. The abdomen is broadly rounded and slightly flattened, while the umbilical shoulders slope steeply inwardly. There are four or five constrictions to a whorl, visible both on the shell and on the cast. These occurred even in the early larval stages, beginning at a diameter of 0.90 mm., and lasting until old age.

[1] Palæontographica, Vol. XXVII. Beiträge z. Entwick. Foss. Ceph., Pl. IV, fig. 1.

The shell is marked with distinct cross striæ of growth, with fine sharp crenulations, which show only toward maturity. The elevations between the pits of the crenulations become in the adult indistinct spiral ridges, giving a finely reticulated aspect to the surface. The cross striæ and spiral ridges are not visible on the cast. In the adult stage the surface is ornamented with undulating growth bands, forming weak ribs strongest near the umbilicus and distinctly visible on the cast. These originate from bundling of the cross striæ at the umbilicus, and give the shell a decided resemblance to the Triassic genus *Juvavites*, which may very possibly be a descendant of *Glyphioceras*. This bundling begins at about 2.3 mm. diameter.

The visible sutures consist of a pair of pointed ventral lobes (divided by a notched saddle) and a pair of angular lateral lobes. All the lobes and the first pair of lateral saddles are angular in the adult, while the second pair of saddles is broadly rounded. A second pair of lateral lobes is on the umbilical shoulders, just concealed by the involution. The internal sutures consist of a pointed antisiphonal or dorsal lobe, and a pair of similar lateral lobes. In the early part of the adult stage the lateral saddles are rounded, as shown on Pl. XV, fig. 11, on a specimen of 15 mm. diameter. In the youthful stages all the saddles are broad and the lobes only slightly pointed.

MEASUREMENT OF SPECIMENS OF ADULT AGE.

	mm.	mm.	mm.	mm.
Diameter	15.00	20.7	23.00	31.5
Height of last whorl	7.25	8.2	12.5	17.0
Height of last whorl from the preceding.	4.00	4.0	....	....
Width of last whorl	12.00	15.7	20.5	24.5
Involution	3.25	4.2	7.5	....
Width of umbilicus	1.70	....	....	....

Position and Locality.—*Glyphioceras incisum* was found in the Fayetteville shale, Warsaw division of the Lower Carboniferous, at Moorefield, Independence County, Arkansas, accompanied by *Nautilus (Endolobus) spectabilis* Meek, *Productus semireticulatus* Martin, *P. cora* d'Orbigny, *Spirifer lineatus* Martin, *S. glaber* Martin, *Terebratula bovidens* Meek, and numerous other less characteristic species. The specimens of *G. incisum* from the Moorefield beds agree exactly with those described by Hyatt from the Bend formation, Carbonferous, five miles west of Lampasas, Texas. In the same paper Hyatt[1] describes *Glyphioceras cumminsi*, also from the Bend formation; he compares *G. cumminsi* to *G. striatum* Sowerby and *G. crenistria* Phillips, finding, however, points of difference from both. European paleontologists now regard *G. striatum* and *G. crenistria* as synonymous, and many go so far as to place both as synonyms under *G. sphæricum* Martin. To this last species Hyatt compares *G. incisum*, but finds that *G. incisum* lacks the crenulations which *G. sphæricum* has, and agrees with it in lacking spiral ridges. *G. incisum* is certainly very nearly related to *G. sphæricum*, and if the European forms *G. crenistria* and *G. striatum* are all identical with *G. sphæricum*, the American form might also very well be classed as a variety under that species, especially as *G. incisum* as an adult has distinct crenulations. The European Carboniferous faunas are turning out to be much more closely related to those of the Mississippi Valley than has been recognized heretofore. In a recent paper the writer[2] has described from the Coal Measures of Arkansas the following European Coal Measure forms not before known in America: *Conocardium aliforme* Sowerby, *Gastrioceras marianum* Verneuil, *Pronorites cyclolobus* Phillips, besides many others known before in America. Thus the presumption is not against the identity of very similar forms in the two regions, but rather in favor of it.

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[1] Op. cit., p. 467, Pl. XLVII, figs. 33-43.

[2] Proc. Am. Phil. Soc., Vol. XXXV, 1896, No. 152, "Marine Fossils from the Coal Measures of Arkansas."

LARVAL STAGES.

In order to obtain the larval stages of *Glyphioceras incisum*, a number of adults were selected, so as to make sure of the identity, and the outer coils were broken off until the desired size was obtained. This necessitated the destruction of several specimens, but was well worth while in view of reliability of the results. The specimens were studied in three different mountings, dry on card-board, in a drop of water on card-board, and in water in a watch-glass over a strong condensing lens. In the first way the surface markings are seen best, in the second the sutures and form, in the third the internal structure when the specimen is translucent. The nomenclature used is that of Hyatt, published in "Phylogeny of an Acquired Characteristic."[1]

Phylembryonic. The protoconch represents the first shell secreted by the shell-gland, and must have been formed while the animal was in the egg. It is quite possible that some of the chambers were formed before the egg was hatched, but this cannot be determined on fossils. The protoconch is taken for convenience to represent the phylembryonic stage of growth, the end of the embryonic, when the class or phylum can be determined, and the animal is already a cephalopod. In shape, the protoconch is a smooth, rather elongate, bobbin-shaped, oval body, of which the upper part projects forward in a lap, where the first chamber was joined to it. The protoconch was not the whole of the embryo chamber, for a part of the spiral tube must have furnished a lodging for the embryo; but after the formation of the first air-chamber it is no longer possible to determine how long the primitive body-chamber was. The protoconch corresponds to the primitive nautilian shell from which the ammonoids descended, but the parallelism is not exact, for the initial chamber of the nautiloids is not calcareous, while acceleration of development has pushed back to the embryo the calcareous shell of the ammonoids.

In the protoconch is seen the beginning of the siphon, or

[1] Proc. Am. Phil. Soc., Vol. XXXII, No. 143.

siphonal *cæcum*, a pear-shaped knob, projecting a short distance into the embryonic shell. It must have been present in the embryo, for it is older than the first suture, but its function is unknown. In some specimens what seemed to be a tube could be seen attached to the *cæcum;* this is probably the prosiphon described by Munier-Chalmas, but no specimens sufficiently definite to figure could be obtained.

On Pl. XIII, figs. 1 and 2, is shown the protoconch from which all the chambers have been broken off. Dimensions:

	mm.
Diameter	0.46
Height of whorl at attachment of first chamber	0.24
Height of first chamber from protoconch	0.17
Width	0.66
Involution	0.07

The protoconch is constant in size and dimensions, for several specimens were obtained free from the air-chambers. Also a number of others were broken back almost to the protoconch, and the dimensions agreed, as nearly as could be determined.

On Pl. XIII, figs. 3, 4, and 5, is shown the protoconch of a *Glyphioceras* from the Carboniferous of Scott County, Arkansas, 2 N., 29 W., section 36, near the center. This species was compared by the writer[1] to *G. sphæricum* Martin, and said to be identical with the species from Moorefield. But although the adults are nearly alike, the protoconchs are quite unlike, as may be seen by a comparison of the two figures. The following are the dimensions of the Scott County form:

	mm.
Diameter	0.53
Height of whorl at attachment to the protoconch	0.26
Height of whorl from the protoconch	0.18
Width	0.80
Involution	0.08

These figures show it to be larger and proportionally broader than the typical *G. incisum*. If the species are identical then this is an unusual variation.

[1] "Marine Fossils from the Coal Measures of Arkansas," p. 11.

Ananepionic. As soon as the first air-chamber is formed the animal has left the embryonic and begun the larval stage, and then takes rank with the chambered nautiloids. The suture at this stage consists of a very broad ventral saddle with a pair of narrow lateral lobes. On Pl. XIII, fig. 1, is shown this suture; fig. 6 shows this and also the second chamber-wall; figs. 9 and 10 show the ananepionic suture with half a coil attached. Pl. XV, fig. 1, shows the initial suture along with the later ones. While this stage cannot be compared to any particular genus, it corresponds to some nautilian form of the Silurian. The ananepionic siphon is about half-way between the dorsum and the venter, in this character, too, agreeing with the nautiloids. Where the siphon passes through the partition the wall is bent backward in a cone and has a siphonal collar around the tube. The surface is still smooth, no ornamentation of any sort ever having been seen on early stages of ammonoids.

Metanepionic. With the second larval substage the shell becomes a true ammonoid; this begins with the second suture, which takes on the ventral lobe of the goniatites. The shell is smooth as before, and the whorl changes little in shape, being still low, broad, and little embracing. The sutures and shape correspond exactly to *Anarcestes*, the primitive goniatite and radicle of the ammonoids. *Anarcestes* was named but not characterized by Mojsisovics,[1] and afterward defined by Hyatt[2] as containing forms with smooth, broad, and low whorls, with semilunular cross-section, deep umbilicus, and rather broad abdomen. *Goniatites subnautilinus* Schlotheim, of the Middle Devonian, was chosen as type of the genus, but most of the species occur in the Lower Devonian, in the Hercynian beds, which were formerly assigned to the Upper Silurian.

Glyphioceras incisum shows the *Anarcestes* stage at the second and third sutures, and resembles closely *A. lateseptatus* Beyrich of the Lower Devonian. On Pl. XIII, fig. 6, is seen the transition from the ana- to the metanepionic;

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[1] "Cephalopoden der Mediterranen Trias-Provinz," p. 181.
[2] "Genera of Fossil Cephalopods," p. 309.

figs. 9 and 10 show the transition from ananepionic (first suture) to metanepionic (second and third sutures); figs. 11 and 12 show the *Anareestes* stage at the first and second sutures visible on the whorl. The metanepionic sutures, seen in projection on Pl. XV, figs. 2 and 3, consist of a deep, rounded, ventral lobe, and a pair of broad, shallow, lateral lobes. When the animal has progressed thus far in its development it is a true goniatite, and the siphon has already turned to the outside of the whorl, or abdomen. On Pl. XV, fig. 12, are shown for comparison the sutures of *A. subnautilinus* (after L. von Buch, Gesammelte Werke, Vol. IV, p. 116, Pl. XI, fig. 9).

Paranepionic. When the broad lateral lobes become indented with a pair of lateral saddles, the sutures, the narrow umbilicus, and the broad, low whorl all correspond to *Tornoceras* Hyatt, of the Middle and Upper Devonian. *G. incisum* reaches this stage at the fourth suture, at a diameter of about 0.68 mm., one-third of a whorl, and continues in it for the fourth, fifth, and sixth sutures, up to a diameter of 0.80 mm., and five-eighths of a whorl. Pl. XIII, figs. 9 and 10, shows the form at the *Tornoceras* stage, at one-half a whorl, with the following dimensions:

	mm.
Diameter	0.74
Height last coil	0.38
Height last coil from the protoconch	0.13
Width of last whorl	0.77
Involution	0.26
Width of umbilicus	0.06

On Pl. XIII, figs. 11 and 12, the *Tornoceras* stage shows at the fourth, fifth, and sixth sutures.

Neanic. When the ammonoid in its growth no longer shows the characters of its distant ancestors, but has already taken on those of its own family, it may be said to have left the larval stage proper and to have begun its youth. The ananeanic is then the beginning of the adolescent period. *G. incisum* at the seventh suture, three-fourths of a whorl, and diameter of 0.85 mm., changes its form markedly; the two pairs of lateral lobes become more pronounced, and

the ventral lobe becomes smaller in proportion; the coil leaves its close spiral and shows decided egression, the umbilicus becomes wider, while the chamber becomes actually narrower than in the *Tornoceras* stage, as seen from these figures: width of chamber at diameter 0.74 mm. is 0.77 mm., at diameter 0.92 mm. it is 0.69 mm. The involution also becomes less. At diameter 0.90 mm. and end of the first whorl a decided constriction, marking a temporary mouth of the shell, makes its appearance. This stage corresponds to the Upper Devonian and Carboniferous genus *Prionoceras* Hyatt,[1] of which *P. divisum* Muenster, of the Upper Devonian, and *P. belvalianum* de Koninck, of the Lower Carboniferous, are the types. These species have broad, low, rather evolute whorls, with wide umbilici and smooth surfaces, ornamented only with periodic constrictions. The external sutures consist of an undivided, pointed, ventral lobe, one pair of angular lateral lobes, and a second pair of rounded lobes on the umbilical border. The external saddles are angular and the lateral saddles rounded and broad. To this genus may also be assigned *Goniatites compactus* Meek and Worthen, Geol. Survey Illinois, Vol. V, p. 611, Pl. XXXI, fig. 2, of the Coal Measures; and *G. greencastlensis* Miller and Gurley, Bull. XI, Illinois State Mus. Nat. Hist., p. 44, Pl. V, figs. 12–14, from the St. Louis group of the Lower Carboniferous. These species differ from the types in the rounded external saddles, but in this respect they agree with the ananeanic substage of *G. incisum*. The beginning of the *Prionoceras* stage is shown on Pl. XIII, figs. 11 and 12, in the widening of the umbilicus, egression of the spiral, and narrowing of the chamber. Dimensions of the specimen:

	mm.
Diameter	0.92
Height of last whorl	0.33
Height of last whorl from the preceding	0.23
Width of last whorl	0.69
Involution	0.10
Width of umbilicus	0.30

[1] "Genera of Fossil Cephalopods," p. 328.

This stage begins at 0.85 mm. diameter, three-fourths of a whorl from the protoconch, and lasts with little change except increase in size for two revolutions up to a diameter of 2.25 mm., when the transition to *Glyphioceras* begins.

Plate XIV, figs. 1 and 2, shows a continuation of the *Prionoceras* stage, at one and three-fourths whorls, with dimensions:

	mm.
Diameter	1.29
Height of last coil	0.45
Height of last coil from the preceding	0.29
Width of last coil	0.95
Involution	0.15
Width of umbilicus	0.50

On this specimen are seen two constrictions about two-thirds of a revolution apart, thus making the resemblance to *Prionoceras* very striking. At this stage are first seen the cross striæ of growth. A continuation of the same generic stage is shown on Pl. XIV, figs. 3 and 4, at one and seven-eighths whorls, and dimensions:

	mm.
Diameter	1.38
Height of last coil	0.52
Height of last whorl from the preceding	0.31
Width of last whorl	1.02
Involution	0.21
Width of umbilicus	0.51

The relative dimensions are nearly the same as at diameters 0.92 mm. and 1.29 mm., but the sutures differ slightly, the ventral lobe being slightly blunted, as shown on Pl. XV, fig. 8. On this specimen only one constriction was visible at diameter of 0.85 mm.

On Pl. XIV, figs. 5 and 6 show a larger specimen still in the *Prionoceras* stage, at two and one-eighth whorls. Dimensions:

	mm.
Diameter	1.64
Height of last whorl	0.60
Height of last whorl from the preceding	0.40
Width of last whorl	1.38
Involution	0.20
Width of umbilicus	0.54

No constrictions were visible on this specimen; that one which occurs at end of the first whorl being concealed by the outer coil. The relative dimensions are nearly the same as on the preceding specimens, except that the last whorl is proportionally broader and the umbilicus narrower. The sutures are the same as on the last specimen. The end of the *Prionoceras* stage is shown on Pl. XIV, figs. 7 and 8, at two and three-fourths of a whorl. Dimensions:

	mm.
Diameter	2.25
Height of last whorl	0.87
Height of last whorl from the preceding	0.50
Width of last whorl	1.82
Involution	0.37
Width of umbilicus	0.58

No constrictions were visible on this specimen, the earlier ones being concealed by the outer whorl. The figures show that the relative dimensions remain nearly as before, but the umbilicus becomes considerably narrower. The sutures are like those of the smaller specimens, but on the last half-whorl the ventral lobe becomes very much flattened, and at diameter of 2.2 mm. becomes slightly indented by the beginning of a ventral saddle, thus showing a transition to *Glyphioceras*, and the end of the adolescent stage. No youthful stages larger than this were successfully broken out in condition to figure, but the imperfect ones obtained showed a gradual narrowing of the umbilicus and increase in height of the whorl and involution.

ADULT STAGE.

The form of the adult *Glyphioceras incisum* has already been sufficiently described in this paper and in Hyatt's monograph. The sutures changed in increasing depth of the ventral sinus and sharpening of the lateral lobes, as shown on Pl. XV, fig. 11, taken from a specimen of diameter of 15 mm. The early adult sutures have been figured by Hyatt, Geol. Survey Texas, Fourth An. Rep., Pl. XLVII, figs. 44-45.

Plate XIV, fig. 9, shows the smallest specimen obtained of the adult stage; it agrees in all essentials with those of larger growth, only the ventral saddle is shorter and the lateral saddles more rounded.

TABLE OF STAGES OF GROWTH.

	Proto-conch.	Proto-conch and two chambers.	One-half whorl, *Anarcestes* to *Tornoceras*	First whorl, *Tornoceras* to *Priono-ceras.*	*Priono-ceras* stage $1\frac{3}{8}$ whorls	*Priono-ceras* $1\frac{5}{8}$ whorls.	*Priono-ceras* $2\frac{1}{8}$ whorls.	*Priono-ceras* $2\frac{3}{8}$ whorls.
	mm.	mm.	mm.	mm.	mm	mm.	mm.	mm.
Diameter........	0.46=1.00	0.61=1.00	0.74=1.00	0.92=1.00	1.29=1.00	1.38=1.00	1.64=1.00	2.25=1.00
Height of last whorl..........	0.24=0.52	0.31=0.50	0.38=0.52	0.33=0.35	0.45=0.34	0.52=0.38	0.60=0 36	0.87=0.38
Height of last whorl from the preceding....	0.17=0.36	0.15=0.24	0.13=0.17	0.23=0.25	0.29=0.22	0.31=0.22	0.40=0.23	0.50=0.22
Width of last whorl..........	0.66=1.56	0.66=1.08	0.77=1.04	0.69=0.75	0.95=0.73	1.02=0.73	1.38=0.84	1.82=0.80
Involution......	0.07=0.15	0.16=0.26	0.26=0.35	0.10=0.10	0.15=0.11	0.21=0.15	0.20=0.12	0.37=0.16
Width of umbilicus...........	....	....	0.06=0.08	0.28=0.30	0.50=0.38	0.51=0.37	0.54=0.32	0.58=0.25

	Prionoceras to *Glyphioceras.*	*Prionoceras* to *Glyphioceras.* End of neanic.	*Glyphioceras.* Anephebic.	*Glyphioceras*
	mm.	mm.	mm.	mm.
Diameter..................	2.60=1.00	3.00=1.00	6.00=1.00	11.00=1.00
Height of last whorl............	1.24=0.47	1.45=0.48	3.50=0.58	5.50=0.50
Height of last whorl from the preceding..	0.76=0.29	0.83=0.27	1.80=0.30	3.00=0 27
Width of last whorl............	2.32=0.88	2.82=0.94	6.00=1.00	10.00=0.90
Involution.................	0.48=0.18	0.62=0.20	1.65=0.27	2.50=0.22
Width of umbilicus............	0.61=0.23	0.66=0.22	0.90=0.15	1.00=0.09

SUMMARY OF RESULTS.

The ontogeny of *Glyphioceras* is of interest not only for its own sake, but also because it is the most important genus of the largest family of ammonoids of the Carboniferous, and because this family gave rise to a large part of the am-

monites of the Trias. *Glyphioceras* in its ontogeny goes through the following stages: phylembryonic, protoconch, representing the primitive cephalopod; ananepionic, Silurian nautiloid; metanepionic, *Anarcestes* of Lower Devonian; paranepionic, *Tornoceras* of Middle Devonian; neanic, *Prionoceras* of Upper Devonian and Carboniferous, showing gradual transition through ana-, meta-, and paraneanic, and a gradual change from *Prionoceras* to *Glyphioceras* in the late adolescent and early adult stages. *Prionoceras* is undoubtedly the family radicle, and *Brancoceras* is a side-branch, since *Glyphioceras* does not go through any stage corresponding to the latter genus. *Gastrioceras* comes from *Prionoceras* (through *Münsteroceras)* by somewhat narrowing the whorl and division of the ventral lobe. *Glyphioceras* comes directly from *Prionoceras* by narrowing the umbilicus so as to conceal most of the inner whorls and by division of the ventral lobe.

The division of the subfamily *Glyphioceratidæ* into *Brancoceras*, *Prionoceras*, *Pericyclus*, *Glyphioceras*, (subgenus *Münsteroceras)*, *Gastrioceras*, *Paralegoceras*, is quite proper for phylogenetic reasons.

According to Steinmann the *Ceratitidæ* of the Trias are descended from *Gastrioceras*, and the *Tropitidæ* from *Pericyclus*, but neither of these groups goes through stages of growth corresponding to these genera. *Tropites* does, however, go through a *Prionoceras* stage, and later it resembles closely *Gastrioceras*, but it already has the *Tropites* keel before the ventral lobe is divided. It then descends from the *Glyphioceratidæ*, but directly from the radicle and not through any modified form. But it is quite likely that some of the genera assigned to the *Tropitidæ* do descend directly from other members of the *Glyphioceratidæ*.

LELAND STANFORD JUNIOR UNIVERSITY,
CALIFORNIA,
October, 1897.

EXPLANATION OF THE FIGURES.

Plate XIII.

All figures on this plate are forty times enlarged.

Glyphioceras incisum Hyatt.

Figs. 1, 2. Protoconch. 1, from above; 2, from front. Diameter 0.46 mm.

Figs. 3, 4, 5. Protoconch of same or a nearly related species from Scott County, Arkansas. 3, from above; 4, from front; 5, from side.

Figs. 6, 7, 8. Protoconch with first two sutures. 6, from above; 7, from front; 8, from side.

Figs. 9, 10. Larval stage, diameter of 0.74 mm., protoconch and one-half of first whorl, showing the first four sutures, from phylembryonic to the paranepionic substage. 9, from side; 10, from front.

Figs. 11, 12. Larval stage, diameter of 0.92 mm., first whorl, showing first eight sutures, and transitions from the metanepionic (*Anarcestes* stage), through paranepionic (*Tornoceras* stage) to ananeanic (*Prionoceras*) stage. 11, from front; 12, from side.

EXPLANATION OF THE FIGURES.

PLATE XIV.

All figures on this plate are twenty times enlarged, except fig. 9, which is twice natural size.

Glyphioceras incisum HYATT.

Figs. 1, 2. Adolescent stage, one and three-fourths whorls, diameter of 1.29 mm., last whorl is ananeanic (*Prionoceras* stage) and shows transition from paranepionic. 1, front; 2, side.

Figs. 3, 4. Adolescent stage, diameter of 1.37 mm., one and seven-eighths whorls, *Prionoceras* stage. 3, from front; 4, from side.

Figs. 5, 6. Adolescent stage, diameter of 1.64 mm., two and one-eighth whorls, *Prionoceras* stage. 5, from front; 6, from side.

Figs. 7, 8. End of adolescent stage, diameter of 2.25 mm.; two and three-fourths whorls; transition from *Prionoceras* to *Glyphioceras* in the division of the ventral lobe, and beginning rounding of the whorl. 7, side view; 8, front view.

Fig. 9. Early adult stage, diameter of 15 mm., twice enlarged.


2


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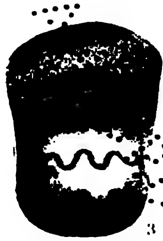
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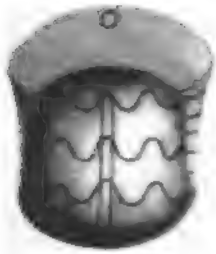
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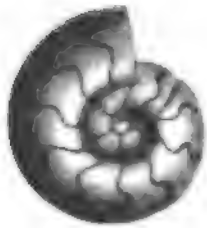
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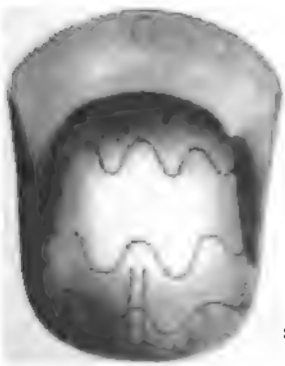
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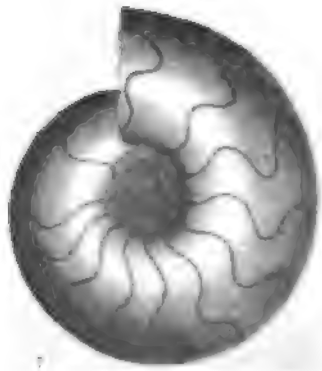
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EXPLANATION OF THE FIGURES.

PLATE XV.

All figures of *Glyphioceras* on this plate are magnified forty times, except fig. 11, which is four times enlarged.

Glyphioceras incisum HYATT.

Fig. 1. First suture, ananepionic.

Fig. 2. Second suture, metanepionic *(Anarcestes)*.

Fig. 3. Third suture, metanepionic.

Fig. 4. Fourth suture, paranepionic *(Tornoceras)*.

Fig. 5. Fifth suture, at one-half a revolution, and diameter of 0.74 mm., paranepionic.

Fig. 6. Eighth suture, at one revolution, and diameter of 0.92 mm., ananeanic *(Prionoceras)*.

Fig. 7. Suture at one and three-fourths revolutions, and diameter of 1.29 mm., ananeanic.

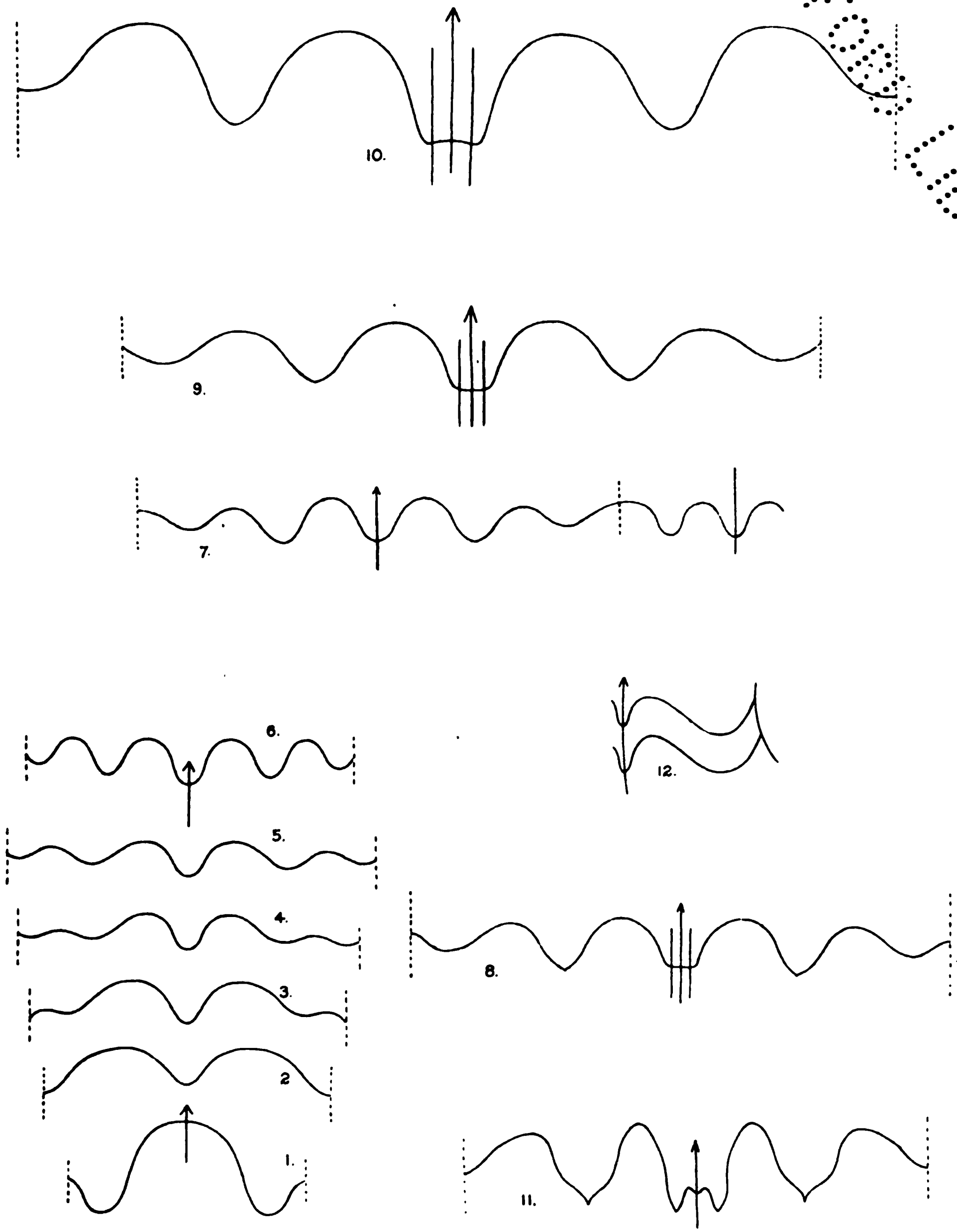
Fig. 8. Sutures at one and seven-eighths revolutions, and diameter of 1.37 mm., *(Prionoceras)*.

Fig. 9. Sutures at two and one-eighth revolutions, and diameter of 1.64 mm., *(Prionoceras)*.

Fig. 10. Sutures at diameter of 2.25 mm., 2¼ whorls, transition from *Prionoceras* to *Glyphioceras*.

Fig. 11. Sutures at diameter of 15 mm., adult.

Fig. 12. Sutures of *Anarcestes subnautilinus*, after L. von Buch, Gesammelte Werke, Vol. IV, p. 116, Pl. XI, fig. 9.



Glyphioceras incisum Hyatt.

Lith Britton & Rey S.F

PROCEEDINGS

OF THE

CALIFORNIA ACADEMY OF SCIENCES.

THIRD SERIES.

GEOLOGY. VOL. I, No. 4.

The Development of Lytoceras and Phylloceras.

BY

JAMES PERRIN SMITH.

WITH FIVE PLATES.

Issued September 20, 1898.

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1898.

THE DEVELOPMENT OF LYTOCERAS AND PHYLLOCERAS.

BY JAMES PERRIN SMITH.

CONTENTS.

INTRODUCTION.

Lytoceras and *Phylloceras* are exceedingly interesting because they are simple, unspecialized genera, long-lived, little changed, and yet with the power of giving off other variable branches. They are the two longest lived genera of ammonites, ranging from about the end of the Trias to the Upper Cretaceous, at least seven millions of years by a conservative estimate. According to most authorities these are the only groups of ammonites in the Jura that do not belong to the stock of the *Arietidæ*, and according to others they are the ancestors of even that stock through *Psiloceras*.

It is in these old, unspecialized genera that we must seek to unravel the genealogical tangle, either in the older for-

 August 29, 1898.

mations, or in survivals of the old types in later times. At first sight it seems a hopeless task ever to work out the family history of the ammonites; for, as Quenstedt once remarked, a man might hope to count the stars of the heavens, or even at a venture the sands of the sea, but the species of ammonities are beyond his ken. But it is just this infinity that gives hope of success; the grading of one form into another by imperceptible steps affords an accurate check on the results of ontogenetic study. And it is quite clear, too, that a few genera furnish the key to the puzzle, since in the later formations the majority of forms were retrogressive and only a few remained simple and progressive.

Because of the interest in *Lytoceras* and *Phylloceras* as persistent types and progenitors of many genera of ammonites in the Jura and Cretaceous, this investigation was undertaken to find out their relationship with each other, and with contemporary genera.[1] If a series of species of *Lytoceras* and *Phylloceras* could be found in all the successive beds of the Jura and Cretaceous it would be comparatively easy to establish in this way a genetic series. But, as Neumayr[2] has shown, they appear sporadically in successive zones, lacking entirely in many, and not forming a genetic series even where they are known. They must, therefore, have been immigrants from some outside region, supposed by Neumayr to have been the ancient Mediterranean sea, or "Thetys" of Suess.

Since it is not possible to get a genetic series of adults, the next best thing is to take some representative species and work out its ontogeny. "The *Ammonoidea* preserve in each individual a complete record of their larval and adolescent history, the protoconch and early chambers being enveloped and protected by later stages of the shell; and by breaking off the outer chambers, the naturalist can in effect cause the shell to repeat its life history in inverse

[1] The writer has been engaged for a number of years in studying the ontogeny of various species of ammonites, representing the most important genera, in comparing ontogenetic stages with preceding forms, and thus in working out the phylogeny of the ammonites.

[2] Jahrb. K. K. Geol. Reichsanstalt, Wien, Bd. XXVIII, 1878, pp. 58–59.

order, for each stage of growth represents some extinct ancestral genus. These genera appeared in the exact order of their minute imitations in the larval history of their descendants, and by a comparative study of larval stages with adult forms the naturalist finds the key to relationships, and is enabled to arrange genera in genetic series."[1] The method used in this investigation is that given in the paper cited above; it was first discovered by Hyatt, and afterwards used by Branco with such valuable results. By this method a series is not pieced out by selecting a number of separate individuals supposed to represent successive stages of the same species, but a number of well preserved individuals is selected, large enough to make sure of the identity of the species, and the specimens are reduced by pulling off the outer coils to any stage desired. The old way was to mount the specimens in Canada balsam on a glass slide, but this is unsatisfactory, for it allows a view in only one direction. The writer has found it much better to keep the small specimens separate in labelled tubes, and to use three different mounts in microscopic study; dry on white cardboard, to study the shape and surface markings; in a drop of water spread out so as not to distort the object, to show the septa; under water in a watch-glass over a strong condensing lense, to study the siphon, inner septa, and other organs when the cast or shell is translucent. The viscosity of water will hold the minute object in any desired position, so a fixed mount is unnecessary.

NOMENCLATURE OF STAGES OF GROWTH.

In order to correlate stages of growth of the individual with generic stages seen in the development of the race, it is necessary to have an exact scientific nomenclature. The most satisfactory is that given by Professor Hyatt in "Phylogeny of An Acquired Characteristic." [2]

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[1] Journal Geol. Vol. V, 1897, No. 5, J. P. Smith, "Comparative Study of Palæontogeny and Phylogeny," p. 517.

[2] Proc. Amer. Phil. Soc., Vol. XXXII, No. 143, pp. 391 and 397.

TABLE OF ONTOGENETIC STAGES.

Stages.		*Stages.*	*Substages.*	*Comparison with Phylogeny.*	
Embryonic	(1)	Embryonic	Phylembryonic	Phylembryonic	
Larval	(2)	Nepionic	Ananepionic Metanepionic Paranepionic	Phylonepionic	Epacme.
Adolescent	(3)	Neanic	Ananeanic Metaneanic Paraneanic	Phyloneanic	
Adult	(4)	Ephebic	Anephebic Metephebic Parephebic	Phylephebic	Acme.
Senile	(5)	Gerontic	Anagerontic Metagerontic Paragerontic	Phylogerontic	Paracme.

With the embryonic stage the paleontologist can do nothing except the very last substage or phylembryo, when molluscs, brachiopods, and other groups begin to secrete their shell; but all later stages are easily accessible in well preserved material.

A classic example of correlation of ontogeny with phylogeny is the genealogy of the Prolecanitidæ, worked out by Karpinsky [1], who has shown that the Carboniferous genus *Pronorites* goes through the following stages: latisellate protoconch, phylembryonic; with the second suture it becomes an *Anarcestes*, nepionic; about the end of the first revolution the *Ibergiceras* stage begins, the end of the larval period; the second revolution corresponds to *Paraprolecanites*, neanic; on the third whorl begins the *Pronorites* stage, adult. Thus with regard to *Pronorites* the genus *Anarcestes* is phylonepionic, *Ibergiceras* is phyloparanepionic, *Paraprolecanites* is phyloneanic. In the same work Karpinsky shows that *Medlicottia* is a direct descendant of *Pronorites*, and in its development goes through all the stages of the ancestral genus and adds still others. The first revolution of *Medlicottia* could not be studied, but the

[1] Mém. Acad. Sci. St. Pétersbourg, 7th Sér., Tome XXXVII, No. 2. "Ammoneen der Artinsk-Stufe."

second corresponded to *Ibergiceras*, metanepionic; on the third whorl was seen the *Paraprolecanites* stage, paranepionic; at end of the third whorl the *Pronorites* stage, beginning of the neanic; on the fourth whorl the *Sicanites* stage, end of neanic; on the fifth whorl *Promedlicottia*, anephebic; and lastly, at end of the fifth whorl, *Medlicottia*, adult in characters, though not yet in size.

In a recent paper the writer[1] has shown that *Glyphioceras* in its development goes through ammonoid stages from *Anarcestes* and *Tornoceras* as a larva, through *Prionoceras* in the adolescent stage, until at diameter of six millimetres it becomes a full-fledged *Glyphioceras*.

LAW OF ACCELERATION OF DEVELOPMENT.

The study of ontogeny would have little interest and meaning if the law of acceleration of development were unknown. This principle was first used by Louis Agassiz as an aid in the systematic study of biology, but it was reserved for Alpheus Hyatt to formulate the law, and to strengthen theory with practical examples based on the study of cephalopods.[2] An exact and comprehensive definition of the law of *tachygenesis* is the following: "All modifications and variations in progressive series tend to appear first in the adolescent or adult stages of growth, and then to be inherited at earlier and earlier stages according to the law of acceleration, until they either become embryonic or are crowded out of the organization, and replaced in the development by characters of later origin." [3] And in a later paper Professor Hyatt has given a more definite statement: "The substages of development in ontogeny are the bearers of distal ancestral characters in inverse proportion, and of proximal ancestral characters in direct pro-

[1] Proc. Cal. Acad. Sci., 3d Ser., Geol., Vol. I, No. 3. "The Development of Glyphioceras and the Phylogeny of the Glyphioceratidæ."

[2] Mem. Boston Soc. Nat. Hist., Vol. I, 1866-7; Proc. Boston Soc. Nat. Hist., Vol. I, 1866. "Parallelism of Individual and Order among the Tetrabranchiate Mollusks."

[3] A. Hyatt, "Genesis of the Arietidæ," Preface, p. IX.

portion to their removal in time and position from the protoconch, or last embryonic stage."[1]

The life history of the ammonites is the best example of the law of tachygenesis; these branched off from the nautiloids near the beginning of Devonian time, continued increasing, diverging, became highly specialized and accelerated until their final extinction at the end of Cretaceous time. Each ammonite goes through a larval history that is long and varied in direct proportion to the length of time from its period back to the Lower Devonian. Thus the Nautilinidæ, the first of the new stock, have a comparatively simple ontogeny, there being no great changes from the larval up to the adult stages. The higher Devonian and Carboniferous forms go through several generic changes before they become adults, and Mesozoic genera have still longer larval and adolescent periods; that is, longer in the sense of more complicated.

A distinct addition to this principle has been made in Cope's idea of *retardation*, by which is explained the separation in the ontogeny of the descendant of characters that occurred simultaneously in the ancestor. Cope says: "The *acceleration* in the assumption of a character, progressing more rapidly than the same in another character, must produce, in a type whose stages were once the exact parallel of a permanent lower form, the condition of *inexact parallelism*. As all the more comprehensive groups present this relation to each other, we are compelled to believe that acceleration has been the principle of their successive evolution during the long ages of geologic time. Each type has, however, its day of supremacy and perfection of organism, and a retrogression in these respects has succeeded. This has no doubt followed a law the reverse of acceleration, which has been called retardation. By the increasing slowness in the growth of the individuals of a genus and later assumption of the characters of the latter, they would be successively lost."[2]

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[1] Proc. Amer. Phil. Soc., Vol. XXXII, No. 143, p. 405.

[2] "Origin of the Fittest," p. 142.

Dr. R. T. Jackson has recognized the value of this principle of retardation in his studies of the pelecypods,[1] and the writer has noted it in unpublished observations on the ontogeny of many species of ammonites.

The law of tachygenesis was first used by Hyatt in the study of cephalopods, and has since been applied successfully to the pelecypods by Jackson; to the echinoderms by Jackson[2]; to the brachiopods by Beecher, J. M. Clarke, and Schuchert[3]; to the crustaceans by Beecher.[4] It is therefore no longer a theory, but a fixed principle of biology, to be used regardless of any bias towards theories of natural selection or adaptation. It is, however, quite true that all workers in paleontogeny are decided adherents of the Neo-Lamarckian school. A summary of the principles and methods of ontogenetic research has been given by the writer in a recent paper.[5]

Family LYTOCERATIDÆ *Neumayr.*

The Lytoceratidæ, as defined by Zittel,[6] contain forms with wide, shallow, umbilici, evolute, scarcely embracing whorls, smooth except for constrictions, fine striæ of growth, and occasional ribs made by varices. They have a divided siphonal lobe, two principal lateral, with almost no auxiliary lobes. Body chamber one-half to two-thirds of a revolution.

In this group are included species from the Upper Trias to the Upper Cretaceous, most of the abnormal retrograde genera such as *Turrilites*, *Baculites*, *and Hamites* being placed here. Paleontologists are not agreed as to the relations of this family with the Phylloceratidæ, some regarding it as descended from that family, others as the ancestral stock from which they sprang, and others still regarding both as widely divergent branches from the Prolecanitidæ.

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[1] Mem. Boston Soc. Nat. Hist., Vol. IV, No. 8, "Phylogeny of the Pelecypoda," p. 381.

[2] Bull. Geol. Soc. Amer., Vol. VII, 1895, "Studies of Palæechinoidea."

[3] Amer. Jour. Sci., Vol. XLIV, Aug., 1892, "Development of Brachiopoda, Part II"; Trans. Conn. Acad. Sci., Vol. IX, March, 1892; and Proc. Biol. Soc. Washington, Vol. VIII, July 13, 1893.

[4] Amer. Jour. Sci., Feb. and March, 1897, and Amer. Geol., Vol. XVI, Sept., 1895.

[5] Jour. Geol., Vol. V, No. 5, July-August, 1897. "Comparative Study of Palæontogeny and Phylogeny."

[6] Handbuch d. Palæont, Bd. II, 1885, p. 440.

Genus **Lytoceras** *Suess.*

Lytoceras in the strictest sense comprises species with wide, shallow, umbilicus, whorls little embracing, and shell rather smooth except for fine ribs made up largely of the striæ of growth, and occasional varices and constrictions; they have a divided siphonal lobe, two lateral and one auxiliary lobe.

It ranges from the Lias to the Upper Cretaceous. According to Steinmann[1], *Lytoceras* is probably descended from *Monophyllites*, classed by many naturalists with the Phylloceratidæ. Zittel[2] in his latest work considers the Lytoceratidæ as direct descendants of the Prolecanitidæ, and therefore not from *Monophyllites*, which he assigns to the Cyclolobidæ. E. von Mojsisovics[3] says that *Lytoceras* sprang from *Monophyllites* s. str., and that *Phylloceras* came from *Mojsvarites*, a subgenus under that same group.

All that has been done on the ontogeny of this genus is the work of Branco[4], who described and figured some of the larval and adolescent stages of *Lytoceras germaini* but did not give the complete development, nor compare these stages with antecedent genera. On the same plate Branco figures some larval stages of (*Lytoceras*) *simonyi* Hauer, but this species belongs to *Monophyllites*. Neumayr considered *Turrilites*, *Baculites*, and several other abnormal ammonoids as derivatives from the Lytoceratidæ; and indeed the larvæ of *Baculites*, as figured by Amos Brown[5], do resemble very closely those of *Lytoceras*, as do also those of certain *Scaphites*, according to unpublished observations of the writer. It is quite likely, however, that *Scaphites* is not monophyletic.

Lytoceras alamedense, sp. nov.

PLATES XVI-XVIII.

This species is evolute, with wide, shallow umbilicus and coils that increase very slowly in size, thus scarcely embracing the preceding. The shell is

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[1] Elemente d. Pal., 1890, p. 420.
[2] Grundzuege d. Pal., 1895, p. 435.
[3] Denk. K. Akad. Wiss. Wien, Bd. LXIII, 1896, p. 95.
[4] Palæontographica, Vol. XXVI, Beitr. Entwick, Foss. Cephal., Pl. VIII, fig. 6.
[5] Proc. Acad. Nat. Sci. Phila., 1891, p. 159, and 1892, p. 136.

almost smooth, but has fine sinuous cross-striæ of growth that bend forward on the abdomen, form a broad backward bend or lobe on the abdominal shoulders, and another forward sinus on the sides. These are exactly parallel to the mouth, which is marked by varices and constrictions. The growth lines scarcely show on internal casts, but the constrictions are quite distinct, showing them to have been formed by thickening the lip of the aperture during periodic cessations of growth. The sculpture of the shell is shown on Pl. XVII, fig. 4, diameter 7.50 mm., three and three-quarters whorls, seven times enlarged. The shell is not smooth during all the stages; up to the end of the first coil it is smooth, then comes a deep constriction, and for an entire coil the shell is ornamented with relatively coarse, single cross-ribs, which end abruptly, and are represented in later growth by occasional irregular varices. The spiral of the adult is shown on Pl. XVII, fig. 6, and a cross-section, early adult stage, on fig. 1.

The septa are like those usually found on *Lytoceras*, a long, divided siphonal lobe, two principal lateral lobes divided into two parts, and an auxiliary lobe on the umbilical border, divided into several small secondary lobes. This is really a part of the internal lateral lobe. All the lateral saddles are deeply divided. Pl. XVIII, fig. 14, shows the outside septa of the largest specimen where they were visible, diameter 7.00 mm.

It is quite likely that the adult grows considerably larger than any specimen obtained, and that the septa grow more complicated than this, but they would undoubtedly be very like these, for they already bear the stamp of maturity. The internal septa at this size could not be made out in detail.

The largest specimen obtained was only 14.5 mm. in diameter, but from about six millimetres up there is little change, so that larger sizes, if found, will probably be like those figured and described in this paper. The cross-section (Pl. XVII, fig. 1) shows that successive whorls become only very gradually higher, and the abdominal shoulders less rounded, so that there is small likelihood of failure to recognize larger specimens of this species. The only other species with which *Lytoceras alamedense* might be confused is an undescribed form collected by Mr. F. M. Anderson at the Forty Nine mine, near Phœnix, Oregon, and that has a lower, broader whorl, and deeper umbilicus at the same size. The young stages of *L. batesi* Trask are slenderer, with rounded aperture like the adult, but with simple adolescent lobes at diameter of 10 mm., and even at that stage almost no impressed zone. They have many

constrictions, which run straight across the whorl, and lack the sinuosity so characteristic of *L. alamedense*. The striæ of growth also run straight across, parallel to the constrictions.

A striking characteristic of *L. alamedense* is the contraction of the chambers after the first whorl, causing a bulging of the protoconch and part of the first coil. This is shown in the cross-section, Pl. XVII, fig. 1, and especially in the larvæ on Pl. XVI, figs. 7 and 8, 9 and 10.

Horizon and Locality:—*Lytoceras alamedense* was found by Dr. L. G. Yates on the Arroyo del Valle, eight miles southeast of Livermore, Alameda county, California, in calcareous sandstone thought to belong to the upper Horsetown beds, the top of the Lower Cretaceous. Associated with it are *Phylloceras onoënse* Stanton, *Lytoceras batesi* Trask, *Desmosceras hoffmanni* Gabb, *Haploceras breweri* Gabb, *Hoplites remondi* Gabb, *Hoplites* nov. sp. off *H. dufrenoyi* d'Orb. of the Gault of France, *Baculites occidentalis* Gabb, and other species not quite so characteristic. The writer has not visited the locality in person, and so cannot vouch for the occurrence of all these species in the same beds. Mr. E. B. Kimball of Haywards at the request of the writer recently made an excursion to the locality, but could find only beds with *Baculites occidentalis* and *B. chicoënsis*. It seems to the writer to be likely that both horizons are present in such close proximity that they were not differentiated in collecting, or possibly the beds may be transitional from Horsetown to Chico.

ONTOGENY.

Phylembryonic stage.—The first stage in reach of the paleontologist is the protoconch, representing the earliest shell secreted by the shell gland. The class or phylum is already recognizable, but it is not possible to do more than compare this stage with the primitive cephalopod. What that was is unknown, although *Tentaculites* has been thought by some naturalists to be the radicle of the group. It is purely arbitrary to assign the protoconch to the end of the

embryonic stage, but some division must be made, and it is made here for convenience, although certainly a part of the spiral tube was taken up by the embryo. There is a remarkable constancy in the size and shape of the protoconch in all the later ammonoids; in all of them it is a smooth, oval body, about one-half millimetre in diameter and three-quarters in breadth. The protoconchs of the earlier ammonoids were almost spherical, but the oval form was soon developed and became a fixed stage, while other stages that came later were entirely lost in ontogeny. This is the only case known to the writer where ammonites in their development skip over certain stages, but it is true of nearly all later Mesozoic genera. In fact, two species of the same genus often do not agree in omission of stages of growth. Some species of *Schlœnbachia*, for instance, go through in regular order all stages from *Anarcestes* up to *Glyphioceras;* others, on the contrary, omit all stages (so far as any record of them in the shell is concerned) between the protoconch and *Glyphioceras*, reaching that at the second septum. The writer has noted that while different individuals of the same species are remarkably constant in reaching the same stage at the same dimensions, especially in the larval period, different species even though very nearly related, usually differ very much in dimensions at corresponding stages. This difference grows more pronounced in the adolescent period, until decided specific characters appear. In other words, specific difference is merely exaggerated individual variation, and this in turn is merely unequal acceleration or retardation of the appearance of certain characters. All variation would seem, then, to depend on Cope's law.

The protoconch of *Lytoceras alamedense* (Pl. XVI, figs. 1 and 2) has a diameter of 0.56 mm., and width of 0.81 mm; in the protoconch is seen the pear-shaped siphonal cæcum or knob at the beginning of the siphuncle (Pl. XVI, fig. 4). This is surely an embryonic feature, being present before the development of the first septum, and probably represents the shrunken, horny covering of the nauti-

loid embryos, while the calcareous shell of the protoconch is an ammonoid character pushed back by acceleration of development until it occurs simultaneously with nautiloid characters. No trace of a prosiphon could be seen on any specimen, although some were nearly as transparent as glass and would surely show this organ in transmitted light.

Ananepionic. With the appearance of the first septum (Pl. XVIII, fig. 1) the animal becomes not merely a cephalopod, but a chambered nautilian shell, and this is regarded as the beginning of the larval period proper. As shown on Pl. XVI, figs. 3 and 4, this suture consists of a rather narrow, rounded, siphonal saddle, flanked by a narrow, lateral lobe and broader, lateral saddle. This stage corresponds to some Silurian nautiloid, and while constant in all ammonoids is of equally short duration in all, lasting for only one septum.

Metanepionic. At the second septum the shell enters the second larval stage, is no longer a nautiloid, but with the development of a siphonal lobe becomes an ammonoid. As Hyatt[1] has shown, this stage has in most ammonites, especially the older forms, an undivided abdominal lobe like that of the Nautilinidæ of the Lower Devonian; but in many later and more highly accelerated genera the stages corresponding to the older goniatites are omitted. Thus in *Lytoceras alamedense* (Pl. XVIII, fig. 2, and Pl. XVI, figs. 4 and 5) at the second septum the abdominal lobe is developed, but it is already divided by a siphonal saddle; this Hyatt thinks corresponds to the Primordialidæ of the Upper Devonian; but all the older goniatites are retrosiphonate, and only in extreme maturity of some late forms like *Glyphioceras* do the siphonal collars point forwards. Now *L. alamedense* is prosiphonate at the second septum, so that this stage cannot correspond to the Primordialidæ, but rather to some of the late transitional goniatites, or to some of the early simple ammonites of the Permian. The shape and external septum resemble *Glyphioceras*, but that genus

[1] "Phylogeny of An Acquired Characteristic," pp. 414 and 415.

has only one internal lateral lobe on each side of the antisiphonal, and the metanepionic stage of *L. alamedense* shows two (Pl. XVIII, figs. 2 and 3, 4 and 5). This character suggests some early ammonite derived from the Prolecanitidæ, differing from the goniatite stock in being prosiphonate.[1] Such a form is seen in *Nannites*, named by Mojsisovics [2] to include some smooth, rounded species with simple goniatitic septa, from the Upper Trias, *Goniatites spurius* Muenster being the type. These forms while not ammonitic in sutures or ornamentation of the shell are prosiphonate. The septa consist of a divided ventral lobe, two external lateral lobes on each side, an internal undivided antisiphonal lobe, and two on each side.

The ontogeny of *Nannites* is unknown, but it probably comes from some member of the Prolecanitidæ; until recently it was not known below the Upper Trias, but Dr. Carl Diener [3] has discovered it in the *Otoceras* fauna of the Lower Trias of the Himalayas; thus *Nannites* must be a survivor of the Permian ammonite fauna, with which, indeed, it agrees in its chief characters rather than with Triassic faunas. *N. hindostanus* Diener (*op. cit.* Pl. VII, figs. 3, 11, 12) is broad, with low whorl, open umbilicus, simple goniatitic lobes and saddles, and shell marked by contractions forming transverse ridges and furrows; between these contractions the shell is covered with fine striæ of growth. The shell laminæ are cut off by the contractions, and sink under the laminæ in front, causing what Diener calls "direct imbrication."

Nannites was classed by Mojsisovics with the Ptychitidæ, but the genus was raised by Diener to a subfamily Nannitinæ; no connection with the Lytoceratidæ has ever been suggested, but the results of this investigation make it quite probable. *L. alamedense* at the second septum enters a stage resembling *Nannites* (Pl. XVI, figs. 3 and 4), and

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[1] In a recent paper, Mém. Soc. Géol. France. Mém. XVIII, 1898, "Etudes sur les Goniatites," Professor E. Haug derives the Lytoceratidæ from *Gephyroceras*.

[2] Abhand. K. K. Geol. Reichsanstalt, Wien, Bd. X, 1882, p. 210.

[3] Mem. Geol. Survey, India, Pal. Indica, Ser. XV, Vol. II, Part I, p. 66.

continues in this for an entire revolution, to diameter 1.21 mm. (figs 5 and 6), during which time it is smooth, low-whorled, broad, with narrow umbilicus. The forward pointing siphonal collars are plainly visible in some specimens, at first short, reaching only about one-sixth of the distance toward the next septum. At one-third of a coil it extends one-fifth forward, and at one and one-fourth coils it extends one-third of the distance toward the next septum.

Paranepionic. At the end of the first whorl a deep constriction marking a temporary mouth of the shell makes its appearance, and the surface ceases to be smooth, takes on fine cross-ribs with fine striæ of growth between them (Pl. XVI, figs. 7 and 8), and at the same time the umbilicus widens. The whorl narrows perceptibly, causing the protoconch and first coil to bulge out, as shown on Pl. XVI, fig. 9 and Pl. XVII, fig. 1.[1] The septa are still goniatitic, and as long as that lasts, up to one and one-third coils, the shell resembles *Nannites hindostanus* Diener; but shortly after the end of the first coil at diameter of 1.58 mm., one and one-twelfth coils, the two internal, lateral lobes begin to coalesce (Pl. XVIII, fig. 6), showing a departure from the *Nannites* stage. At one and one-third coils, diameter 1.81 mm., the two lobes have grown into one, and the siphonal lobe becomes slightly notched (Pl. XVIII, fig. 7), that is, begins to be ammonitic. The sculpture remains just the same from the end of the first whorl to that of the second (Pl. XVI, figs. 7 and 8, 9 and 10), but progression is very apparent in the development of the septa. Hyatt[2] says that the limits between the larval and adolescent stages in the Lytoceratinæ should be drawn where the septa become ammonitic. To do this here would be artificial, for the sculpture lasts until the end of the second whorl, then stops suddenly, marking a distinct change regarded as the end of the larval period. At diameter of 1.87 mm., one and five-twelfths coils (Pl. XVIII, fig. 8), the lateral

[1] This stage resembles *Pericyclus* of the Lower Carbouiferous, but probably there is no real kinship.

[2] "Phylogeny of An Acquired Characteristic," p. 416.

lobe becomes indented and the saddles somewhat irregular; at diameter of 2.00 mm., one and seven-twelfths coils (fig. 9), this is more pronounced; at diameter of 2.03 mm., one and two-thirds coils (fig. 10), the threefold division of the first lateral lobe is seen; at two coils, diameter of 2.37 mm. (fig. 11), the lobes and saddles, while still comparatively simple, show all the main characters of the Lytoceratidæ, and as the sculpture ends here this may justly be taken as the end of the larval stage.

The paranepionic sculptured whorl may then be divided into two distinct periods: first, that part which has simple goniatitic septa, lasting one-third of a coil; secondly, that part with ammonitic septa, beginning at one and one-third coils and lasting two-thirds of a revolution. This in turn might be subdivided into several subordinate divisions based on increasing complexity of the septa. No descendants of *Nannites* with which this part of the larval stage could be correlated are known.

Adolescent Stages.

When the sculpture dies away and the shell becomes smooth again, the adolescent period may be said to have begun. This happens at the end of the second whorl, and was found on a number of specimens, to be constant at diameter 2.3 mm. On Pl. XVI, figs. 11 and 12, is shown the beginning of this stage, and the corresponding septa on Pl. XVIII, fig. 12. On this specimen the first whorl is smooth (metanepionic), the second sculptured, although since the outer shell is broken off from most of the surface the sculpture is indistinct and shows itself chiefly in undulations rather than ribs on the cast. The characters of the family Lytoceratidæ have now appeared, and this beginning of the neanic period represents *Monophyllites* of the Trias, and closely resembles the group of *M. suessi* Mojsisovics, characterized by the presence of two lateral and one auxiliary lobe. Mojsisovics[1] says that *Lytoceras* comes

[1] Denk. K. Akad. Wiss. Wien, Bd. LXIII, 1896, p. 95.

from the group of *Monophyllites sphærophyllus* Mojs., but that group has two or three auxiliary lobes and could not have given rise to the simpler form without showing the reduction in ontogeny.

It was not found convenient to subdivide the adolescent stage, for the reason that there was no marked change in the surface or shape of the whorl. The septa become gradually more complex until near the end of the third coil they are transitional from *Monophyllites* to *Lytoceras* (Pl. XVII, figs. 2 and 3; Pl. XVIII, fig. 13). This stage lasts for about two revolutions, until near the end of the fourth coil.

Ephebic Stage.

No line can be drawn between the adolescent and adult stages in this species, for the only change is in the gradually increasing digitation of the septa. At three and three-quarters coils, diameter of 7.50 mm., the septa are already typical of *Lytoceras* (Pl. XVIII, fig. 14), while the form has changed little, except that the whorl is slightly higher in proportion to its width (Pl. XVII, fig. 4). The shell is smooth except for the fine cross-striæ and occasional varices. The involution, always slight, becomes almost nothing, and the whorl is somewhat squarer. Pl. XVII, fig. 6, shows the spiral of the largest specimen obtained, diameter of 14.5 mm., with the relative height of whorl and width of umbilicus the same as in the adolescent period. The siphonal collars now reach three-fourths of the distance forward towards the next septum, longer than those described from any other ammonite. These certainly are separate organs and not merely a prolongation of the septal walls.

TABLE OF STAGES OF GROWTH.

	Phylembryonic.	*Nepionic.*				*Neanic.*				*Ephebic.*	
	Protoconch	3/5 coil.	1 coil.	1 1/5 coils.	1 3/5 coils.	2 1/5 coils.	2 5/8 coils.	3 1/8 coils.	3 3/8 coils.	3 3/4 coils.	5 coils.
	mm.	mm.	mm.	mm.	mm.	mm.	mm.	mm.	mm.	mm.	mm.
Diameter	0.56	1.04	1.21	1.81	2.15	3.00	3.90	4.52	6.40	7.50	14.50
Height of last whorl.		0.41	0.45	0.58	0.62	0.95	1.05	1.58	2.26	2.50	4.70
Height of last whorl from preceding.		0.30	0.38	0.50	0.52	0.80	0.82	1.22	1.37	1.90	4.30
Width	0.81	0.86	0.81	1.13	1.16	1.37	1.85	2.07	2.48	3.10	5.20
Involution		0.11	0.07	0.08	0.12	0.15	0.23	0.36	0.89	0.40	0.40
Width of umbilicus.		0.20	0.43	0.95	0.98	1.40	1.97	2.04	2.30	3.30	6.20

MEASUREMENTS OF CROSS-SECTION.

	Nepionic.				*Neanic.*				*Ephebic.*
	Prot. and 1/8 coils.	Prot. and 1/3 co ls.	1 1/8 coils.	1 3/8 coils.	2 1/8 coils.	2 3/8 coils.	3 1/8 coils.	3 5/8 coils.	4 1/8 coils
	mm.	mm.	mm.	mm.	mm.	mm.	mm.	mm.	mm.
Diameter	0.81	1.10	1.55	2.05	2.72	3.66	4.55	6.53	8.60

Genus Phylloceras *Suess.*

Phylloceras, as defined and restricted by Zittel and Steinmann, comprises involute, compressed, high-whorled species, with smooth sides, rounded abdomen, and narrow umbilicus. The septa are branching, leaf-like, have three or four lateral, and at least as many more external auxiliary lobes.

This genus in its typical form appears first in the Lower Jura, but its forerunners are known in the Trias; Zittel[1] says it developed out of *Megaphyllites*, which he assigns to the Cyclolobidæ; Steinmann[2] agrees with Zittel in this, and further derives the family Phylloceratidæ from the goniatite group Prolecanitidæ. J. F. Pompeckj[3] says that *Phylloceras* in its ontogeny goes through stages corresponding to *Megaphyllites* and *Monophyllites*, subgenus *Mojsvarites*, basing his statements on the drawings of Branco. The latest published opinion is that of E. von Mojsisovics[4], who derives *Phylloceras* through *Rhacophyllites* from *Mojsvarites;* he says that *Megaphyllites* belongs to a group with accelerated development betokening degeneration, and that it, with its closed umbilicus, could not have been the ancestor of *Phylloceras* with open umbilicus. From all this it may be seen that there is almost as little agreement about the derivation of *Phylloceras* as of *Lytoceras*.

The only ontogenetic studies yet published on the Phylloceratidæ have been made by Branco[5], on *Megaphyllites insectum* Mojs., protoconch and four septal stages (*op. cit.*, Pl. VII, fig. 4); *M. humile* Mojs. (Pl. VIII, fig. 1), protoconch; *Phylloceras heterophyllum* Sowerby (Pl. IX, fig. 1), protoconch and part of the larval stages; *P. tatricum* (fig. 2), protoconch; *Rhacophyllites tortisulcatus* d'Orb. (fig. 3), protoconch and early larval stages. On these few data have been based all the speculations as to the phylogeny of *Phylloceras*, in so far as they have been based on ontogenetic study at all. Branco and most of the other writers on this subject have assumed that the protoconch is the important stage in ontogeny, and have neglected the later stages. But the protoconch is a fixed stage, remarkably constant in all the later ammonoids, while what Hyatt calls epembryonic stages, and especially the larval and early adolescent stages, are really the important ones; they show most distinctly the characters of ancestral genera.

[1] Handbuch d. Pal., Bd. II, 1885, p. 436.
[2] Elemente d. Pal., 1890, p. 418.
[3] N. Jahrb. f. Mineral, Bd. II, 1895, pp. 19 and 22, "Ammoniten des Rhät."
[4] Denk. K. Akad, Wiss. Wien, Bd. LXIII, 1896, p. 95, "Ceph. Ob. Trias des Himalayas."
[5] Palæontographica, Bd. XXVI, "Beitr. Entwick. Foss. Cephalopoden."

Phylloceras onoënse *Stanton.*

PLATES XIX AND XX.

Phylloceras ramosum GABB, Pal. Cal., Vol. I, p. 65, Pl. XI, fig. 12; Pl. XII, fig. 12.
Phylloceras onoënse STANTON, Bull. 133, U. S. Geol. Survey, p. 74.
(Not *P. ramosum* MEEK, Bull. Geol. and Geog. Survey Terr., Vol. II, No. 4, p. 371.)

This species from the Horsetown beds of the Lower Cretaceous was identified by Gabb with Meek's species from the Upper Cretaceous of Puget Sound. But Dr. Stanton has recently broken this up into three species in a genetic series, *P. knoxvillense* Stanton, from the Knoxville beds, Lower Cretaceous; *P. onoënse* Stanton, Horsetown beds, Gault; and the real *P. ramosum* Meek, from the Upper Cretaceous. Stanton says that *P. onoënse* differs from *P. knoxvillense* in lacking constrictions, but these were observed on several specimens from Cottonwood creek, Shasta county, and from Alameda county.

ONTOGENY.

Larval stages.—No protoconch was separated from the later chambers, but its shape can easily be seen on Pl. XIX, fig. 1, and Pl. XX, fig. 1. It is very like that of *Lytoceras alamedense*. The ananepionic stage, shown by the nautiloid septum (Pl. XX, fig. 1), shows a broader and longer abdominal saddle than *Lytoceras*, but is otherwise like it; the pear-shaped siphonal cæcum or knob could be seen clearly inside of the protoconch. The metanepionic stage lasts only through the second septum (Pl. XX, fig. 1); it has an undivided, rounded, ventral lobe, and two external lateral lobes, and probably corresponds to the stock Prolecanitidæ, from which *Phylloceras* came.

With the third septum comes the divided ventral lobe of the paranepionic stage (Pl. XX, fig. 1); this agrees with the *Nannites* stage of *Lytoceras*, and probably shows the connection with that genus. This stage lasts up to diameter of 1.15 mm., one and five-twelfths coils, is smooth except for a constriction at end of the first coil. Its lobes are

shown on Pl. XX, figs 1 and 2, and the shell on Pl. XIX, figs. 2 and 3. Even at this early stage the tendency to form auxiliary lobes shows itself, in contradistinction to *Lytoceras*. At one and one-sixth coils, diameter of 0.87 mm., the second internal lateral lobe has divided into two, the outer of which soon gets above the umbilical margin. This goes on repeating itself in later stages until a large number of auxiliary internal and external lobes have been formed. The first part of the paranepionic stage lasts up to one and five-twelfths coils, but the umbilicus is always wider than at corresponding stages of *Lytoceras*, and the resemblance to *Nannites* not nearly so great. At this time the lobes begin to be slightly ammonitic, and at one and three-quarters coils, diameter of 1.42 mm. (Pl. XX, fig. 3), are already decidedly so. The species has now parted company with *Lytoceras*, for the lobes are too numerous, and the sculptured stage of that genus is never reached.

Towards the end of the second whorl this form has a moderately wide umbilicus and ammonitic lobes, and then seems to be transitional to that group of *Monophyllites* with several lateral lobes; but at the beginning of the third coil the umbilicus becomes narrower, the last whorl higher and more compressed, and the shell resembles *Megaphyllites*, a Triassic genus which has been shown by Branco[1] to go through in its development stages of growth somewhat like those described for *Phylloceras*. This is the adolescent period, and is shown on Pl. XIX, figs 6–8 and Pl. XX, figs. 4 and 5. Shortly after this the septa become still more complex, transitional to *Phylloceras* (Pl. XIX, fig. 9, and Pl. XX, fig. 6), although the adolescent period does not end abruptly, but at diameter of 7.00 mm. is still quite apparent (Pl. XIX, fig. 10, and Pl. XX, fig. 7). At 10.00 mm. diameter the outline and septa are already characteristic of *Phylloceras*, and even of this particular species, as shown on Pl. XIX, fig. 11. The adult septa shown on Pl. XX, fig. 8, were traced from two photographs, at

[1] Beitr. Entwick, Foss. Cephal., Pl. VII, fig. 4.

diameter of 35.00 mm.; these do not agree perfectly with those figured by Gabb, but in the photograph there was no chance for error as in free-hand sketching. The number and position of the internal lobes are merely indicated by a dotted line, as the details could not be made out.

TABLE OF STAGES OF GROWTH.

	Larval.				*Adolescent.*				*Adult.*	
	P. & 4 septa	$1\frac{1}{6}$ coils.	$1\frac{5}{12}$ coils.	$1\frac{3}{4}$ coils.	$2\frac{1}{6}$ coils.					
	mm.	mm.	mm.	mm.	mm.	mm.	mm.	mm.	mm.	mm.
Diameter	0.44	0.87	1.15	1.42	1.90	2.46	4.30	7.00	10.00	35.00
Height of last coil. . . .	0.28	0.36	0.45	0.53	1.02	1.25	2.12	3.80	6.20	18.50
Height of last coil from preceding	0.14	0.26	0.39	0.41	0.63	0.85	1.40	2.00	3.50	12.00
Width	0.63	0.66	0.66	0.83	1.33	1.50	2.15	3.35	5.30	15.00
Involution.	0.16	0.10	0.06	0.12	0.39	0.40	0.72	1.80	2.70	6.50
Width of umbilicus . . .		0.27	0.41	0.48	0.38	0.53	0.60	0.65	0.50	2.00

CONCLUSION.

In the preceding pages it has been shown that *Lytoceras* in its development goes through the following stages: phylembryonic, protoconch representing some unknown cephalopod; ananepionic, representing some Silurian nautiloid; metanepionic, already an ammonite, and corresponding to *Nannites*, or to some other early genus of the Cyclolobidæ; paranepionic, at first corresponding to the sculptured group of *Nannites*, and later transitional to the earlier members of the Lytoceratidæ; neanic, analogous to that group of *Monophyllites* with two lateral lobes, and transitional to the adult characters of *Lytoceras* at diameter of 7.00 mm.

Phylloceras begins life just as did *Lytoceras*, coming from the same remote ancestor, and agreeing with that genus in

the phylembryonic and ananepionic stages; but at the second septum, metanepionic, it shows the undivided ventral lobe of the Prolecanitidæ, a stage which *Lytoceras* omits. In the paranepionic stage *Phylloceras* also corresponds to some genus like *Nannites*, and continues in this stage up to about one and a quarter coils, although even at this early stage it is distinguished from *Lytoceras* by the tendency to form auxiliary lobes. In the adolescent period *Phylloceras* also goes through a *Monophyllites* stage, but is analogous to that group with narrower umbilicus, and numerous auxiliary lobes, probably to the subgenus *Mojsvarites*. Before the end of the adolescent stage it corresponds to *Megaphyllites* and then by imperceptible transitions, narrowing the umbilicus and complicating the lobes until at 10.00 mm. diameter it becomes a full-fledged *Phylloceras*.

Thus these two genera come from a common origin, and follow the same paths up to *Nannites*, where they part company, each going through a stage corresponding to that genus, but to different species under it; both go through *Monophyllites* stages, but here again analogous to different groups and even different subgenera. There the resemblance ceases, and they develop into different families probably by the middle of the Trias, for in the upper division of that formation *Megaphyllites* and *Monophyllites* are sharply distinguished from each other. In the life-history of these two genera we have a rare opportunity of observing acceleration of development, and divergence of two nearly related stocks, whose history may be traced from the Paleozoic to near the end of the Mesozoic eras.

STANFORD UNIVERSITY,
CALIFORNIA,
May, 1898.

EXPLANATION OF THE FIGURES.

PLATE XVI.

Larval Stages of *Lytoceras alamedense*, sp. nov.

Figs. 1, 2. Protoconch, from above, and front, $^{20}/_1$.

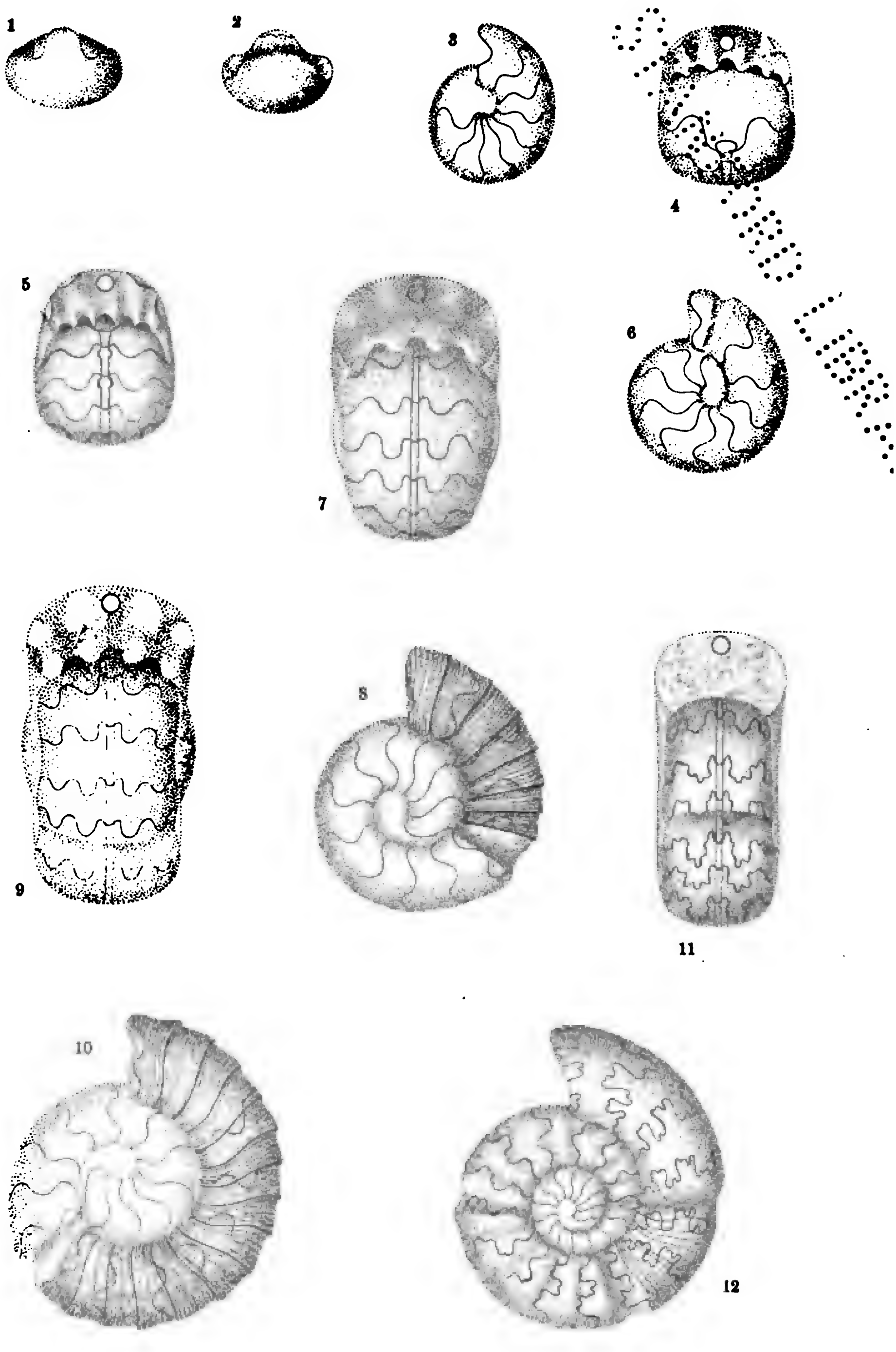
Figs. 3, 4. Protoconch and two-thirds of a coil, diam. of 1.04 mm., twenty times enlarged. Phylembryonic to metanepionic, twenty times enlarged.

Figs. 5, 6. First whorl, diam. 1.21 mm., metanepionic, twenty times enlarged.

Figs. 7, 8. One and one-third coils, diam. 1.81 mm., metanepionic to to paranepionic, twenty times enlarged.

Figs. 9, 10. One and two-thirds coils, diam. 2.15 mm., metanepionic, through paranepionic, to ananeanic; twenty times enlarged.

Figs. 11, 12. Neanic (adolescent), two and one-third coils, thirteen times enlarged, diam. 3.00 mm.



LITH. BRITTON & REY. S

EXPLANATION OF THE FIGURES.

PLATE XVII.

***Lytoceras alamedense*, sp. nov.**

Fig. 1. Cross-section, early adult stage; diam. 8 mm., ten times enlarged, four and one-eighth coils.

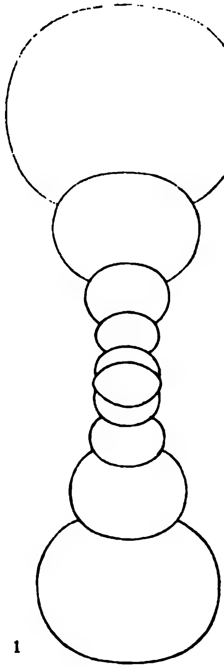
Fig. 2. Spiral, late adolescent stage, diam. 3.90 mm., two and three-quarters whorls, thirteen times enlarged.

Fig. 3. Front outline of the same, diam. 3.90 mm.

Fig. 4. Side view, early adult stage, diam. 7.50 mm., three and three-quarters coils, seven times enlarged.

Fig. 5. Front outline of the above (7.50 mm.).

Fig. 6. Spiral, adult, diam. 14.5 mm., five whorls, four times enlarged.



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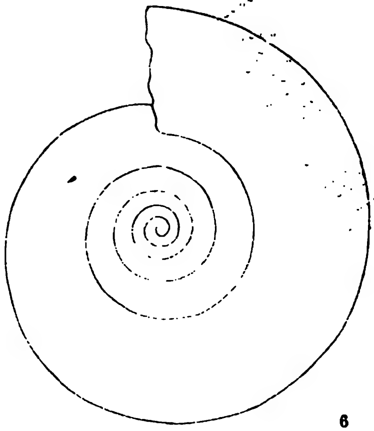

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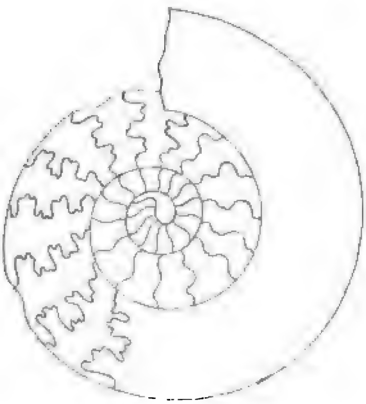

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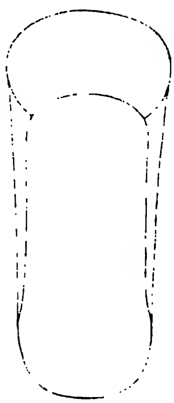

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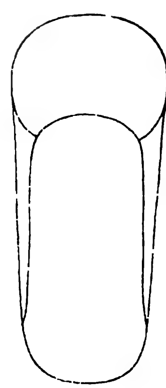

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LITH. BRITTON & REY, S.F.

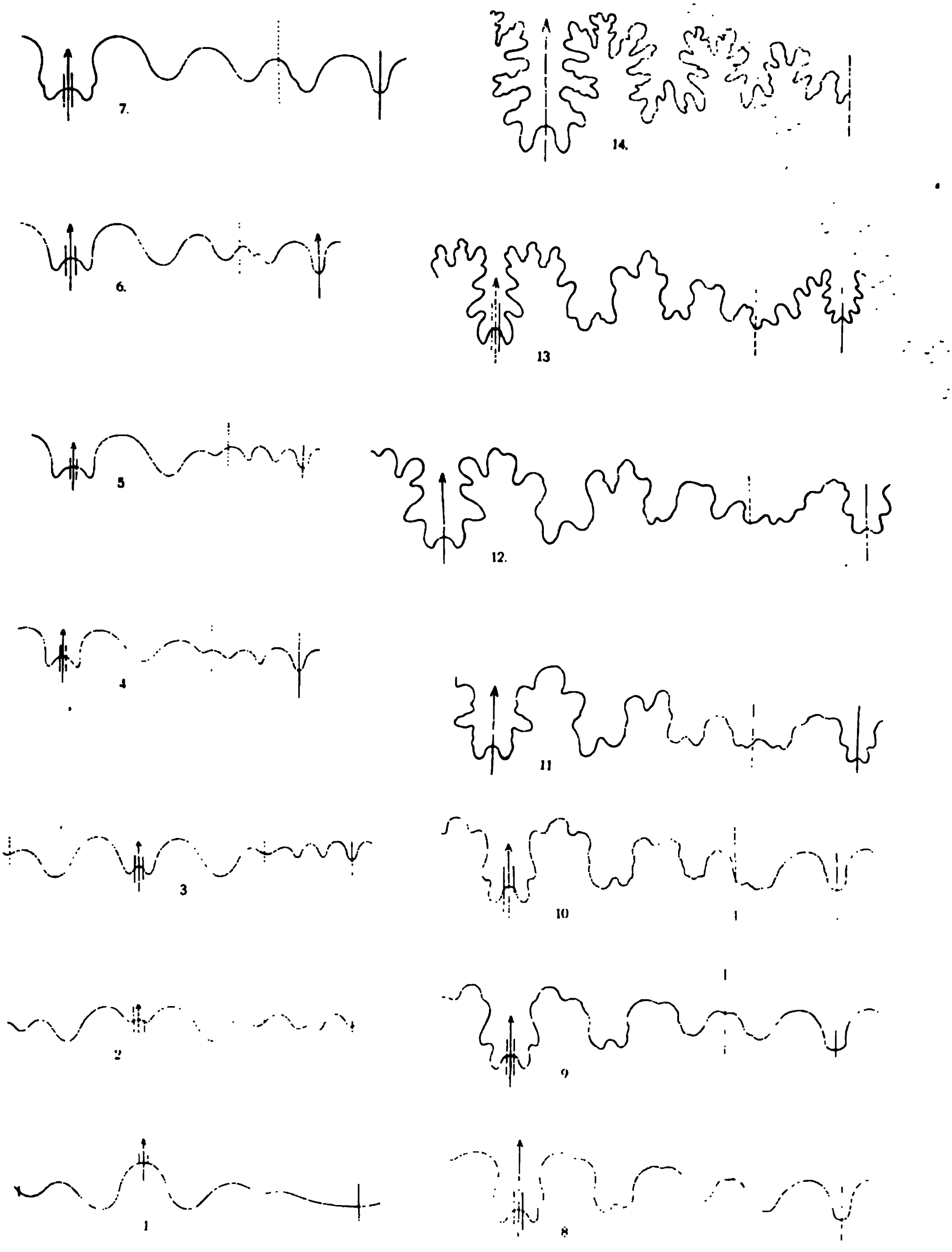
EXPLANATION OF THE FIGURES.

PLATE XVIII.

Figs. 1-12 are thirty times enlarged; fig. 13 is twenty times enlarged; and fig. 14 is fifteen times enlarged.

Development of the septa of *Lytoceras alamedense*, sp. nov.

Fig. 1. First septum.
Fig. 2. Second septum.
Fig. 3. Seventh septum, one-half coil.
Fig. 4. At two-thirds of a coil, diam. 1.04 mm.
Fig. 5. At one coil, diam. 1.21 mm.
Fig. 6. At one and one-twelfth coils, diam. 1.58 mm.
Fig. 7. At one and one-third coils, diam. 1.81 mm.
Fig. 8. At one and five-twelfths coils, diam. 1.87 mm.
Fig. 9. At one and seven-twelfths coils, diam. 2.00 mm.
Fig. 10. At one and two-thirds coils, diam. 2.03 mm.
Fig. 11. At two coils, diam. 2.37 mm.
Fig. 12. At two and one-third coils, diam. 3.00 mm.
Fig. 13. At two and five-sixths coils, diam. 3.90 mm.
Fig. 14. At three and three-quarters coils, diam. 7.50 mm.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EXPLANATION OF THE FIGURES.

PLATE XIX.

Phylloceras onoënse STANTON.

Fig. 1. Protoconch and three chambers, diam. 0.45 mm., front view, forty times enlarged.

Figs. 2, 3. Larva, one and one-sixth coils, diam. 0.87 mm., forty times enlarged.

Figs. 4, 5. Larva, one and three-fourths coils, diam. 1.42 mm., twenty times enlarged.

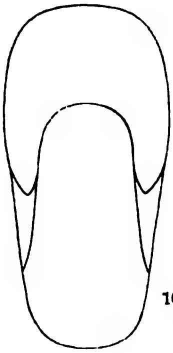
Figs. 6, 7. Transition from larval to adolescent stage, two and one-sixth coils, diam. 1.90 mm., twenty times enlarged.

Fig. 8. Outline at diam. 2.46 mm., twenty times enlarged, adolescent stage.

Fig. 9. Outline at diam. 4.50 mm., thirteen times enlarged.

Fig. 10. Outline at diam. 7.00 mm., seven times enlarged.

Fig. 11. Outline at diam. 10.00 mm., four times enlarged.



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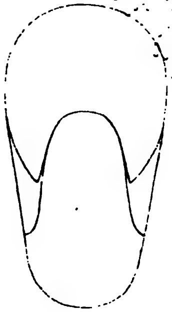

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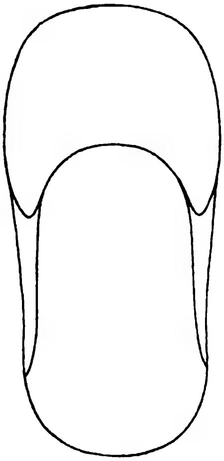

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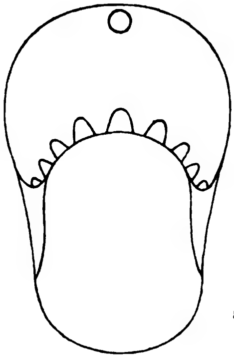

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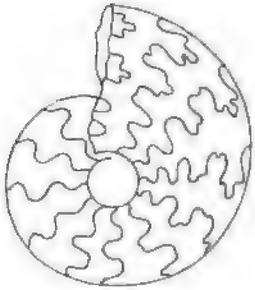

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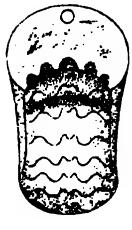

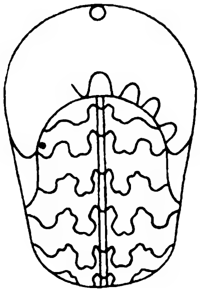

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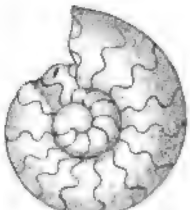

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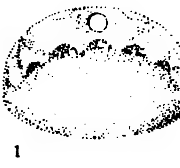

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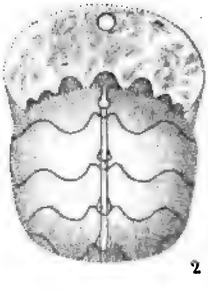

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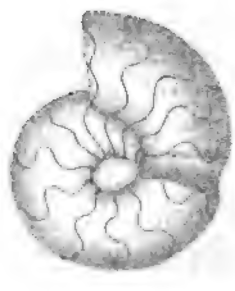


3

EXPLANATION OF THE FIGURES.

Plate XX.

Development of the Septa of *Phylloceras onoënse* Stanton.

Fig. 1. Protoconch, with the first four septa, drawn as if unrolled, forty times enlarged, transition from phylembryonic, through ana-, to meta-, to para-nepionic.

Fig. 2. Diam. 0.87 mm., one and one-sixth coils, forty times enlarged.

Fig. 3. Diam. 1.42 mm., one and three-fourths coils, transition from larval to adolescent stage, forty times enlarged.

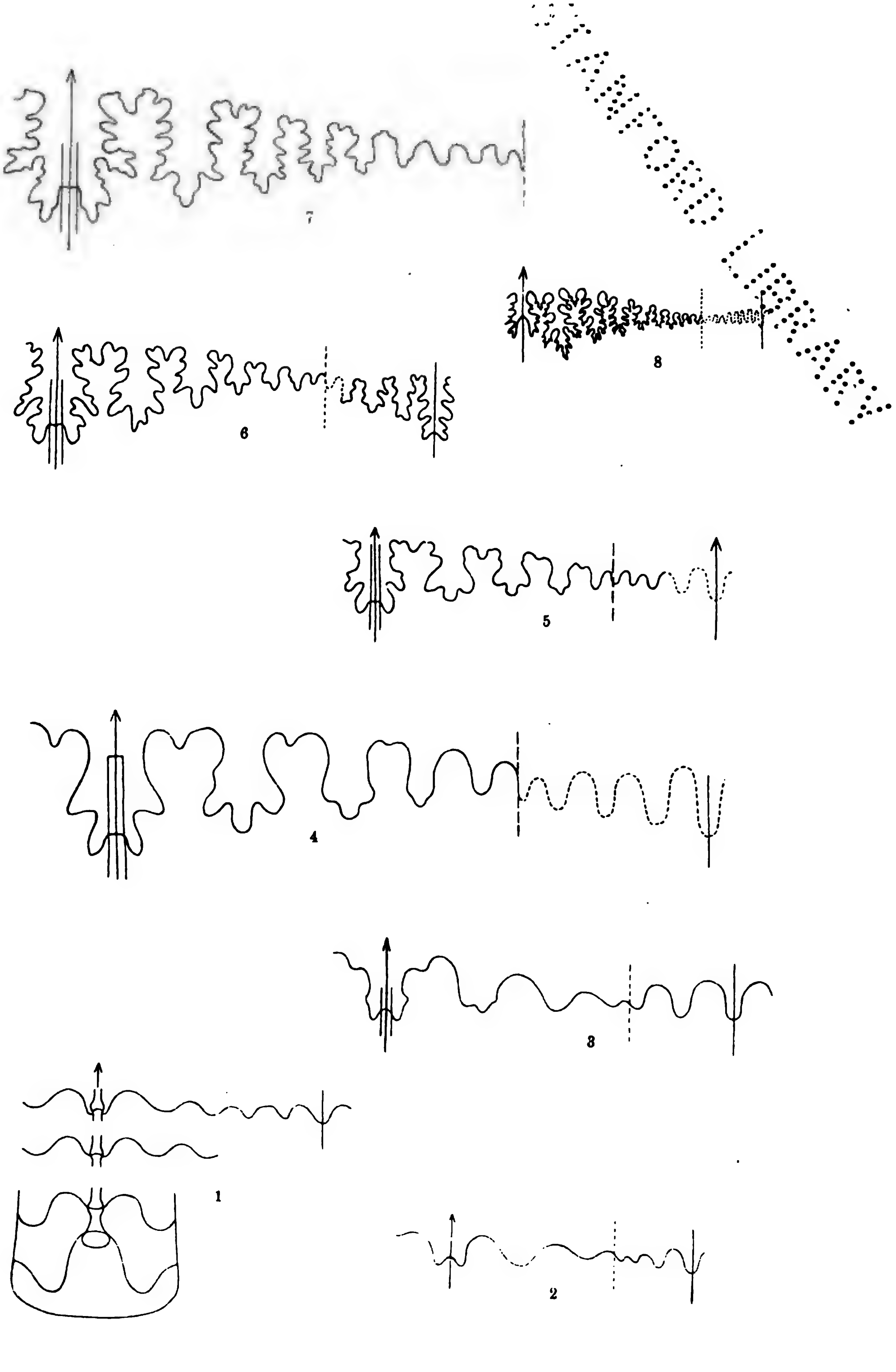
Fig. 4. Diam. 1.90 mm., two and one-sixth coils, forty times enlarged; adolescent.

Fig. 5. Diam. 2.46 mm., twenty times enlarged.

Fig. 6. Diam. 4.50 mm., thirteen times enlarged.

Fig. 7. Diam. 7.00 mm., thirteen times enlarged.

Fig. 8. Diam. 35.00 mm., natural size, adult stage; traced from photographs.



F.R. SMITH, DEL.

PHYLLOCERAS ONOENSE STANTON

PROCEEDINGS

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CALIFORNIA ACADEMY OF SCIENCES.

THIRD SERIES.

GEOLOGY. VOL. I, No. 5.

The Tertiary Sea-Urchins of Middle California.

BY

JOHN C. MERRIAM.

WITH TWO PLATES.

Issued March 6, 1899.

SAN FRANCISCO:
PUBLISHED BY THE ACADEMY.
1899.

THE TERTIARY SEA-URCHINS OF MIDDLE CALIFORNIA.

BY JOHN C. MERRIAM.

CONTENTS.

PLATES XXI–XXII.

I. INTRODUCTION.

IN THE course of an investigation of the invertebrate faunas of Middle California, the writer has found the existing figures and descriptions of the sea-urchins either incomplete or inaccurate to such an extent as to make desirable their reintroduction to those interested in the palæontology of this region. The writer by no means desires to cast reflections on the work of those who first brought the species to light, realizing that with abundant material at hand it is much easier to revise than is the work of original description.

Both geologically and biologically the sea-urchins are among the most deserving of attention of the Californian invertebrates. The comparatively short vertical range of the species, together with their usually good preservation, makes them admirable horizon determiners, while the intimate relationship of some of the forms to each other indicates considerable possibilities in the study of the history and evolution of the clypeastroid branch of the class on this coast, when the faunas of adjoining regions are better known.

March 3, 1899.

II. HISTORY AND RELATIONSHIPS OF SPECIES.

The one new species, *Schizaster Le Contei*, Pl. XXI, fig. 1, here added to the list of forms known from Middle California, is of special interest, as it occurs in the lowest Tertiary, Martinez, and represents a family not known in this region later than that time. It seems to be confined to the Martinez and serves as a characteristic fossil of that formation.

The Tejon formation, resting on the Martinez and forming the upper portion of the Eocene on the Pacific Coast, is not known to contain any echinoid remains, though they may be expected to appear in later collections.

In the Miocene the Clypeastridæ begin and they continue as the only representatives of the class up to the beginning of the Recent period.[1] The oldest certainly known form of this family is *Clypeaster* (?) *Brewerianus*,[2] Pl. XXI, fig. 2, of the Contra Costa County Miocene. This species is small and shows no specialized characters, and, as will be shown later, is probably the ancestor of some of the younger forms.

In what have been considered the lowest beds of the San Pablo formation, immediately overlying the Miocene of Contra Costa County, is found the oldest species of the more specialized division of the Clypeastridæ included in the subfamily Scutellinæ. This species, *Scutella Gabbi*,[3] Pl. XXII, fig. 5, is structurally considerably removed from *Clypeaster Brewerianus* and it is doubtful whether they are nearly related. The *Scutella* is probably an immigrant from some other region.

Immediately above the *Scutella* beds the characteristic San Pablo species, *Astrodapsis tumidus*, Pl. XXI, fig. 3, is very abundant. The *Scutella* and *A. tumidus* have been

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[1] A new species of regular sea-urchin has recently been discovered by Dr. H. W. Fairbanks in the Miocene of southern California. Such forms may also have been represented in middle California, but as the middle and southern portions of the State show in general quite different faunas, we cannot from this occurrence draw any definite conclusions as to the existence of such forms farther north.

[2] *Echinarachnius Brewerianus* of earlier writers.

[3] *Clypeaster Gabbi* of earlier writers.

seen in abundance within less than ten feet of each other and may be found to overlap. *A. tumidus* does not show much affinity to *S. Gabbi*, but is closely related to the older form, *Clypeaster Brewerianus*. From this species it is distinguished mainly by the strong relief of the petals, and it is probable that *C. Brewerianus* is the ancestor of *A. tumidus*. Since in the sequence of strata the beds with *S. Gabbi* lie between those containing these two species, and *Clypeaster* was absent during the intervening period, the modification or evolution was probably brought about in some other region, *Astrodapsis* afterwards coming in to replace the disappearing *Scutella*. Closely related to *A. tumidus* is the larger and thinner *A. Whitneyi*, Pl. XXI, fig. 4, which probably belongs to the later portion of the San Pablo. Both species were confined to this epoch, and with their extinction the more generalized Clypeastroids disappeared from this region. Along the line of descent from *Clypeaster Brewerianus* through *Astrodapsis tumidus* to *A. Whitneyi* the gradual increase in size is quite noticeable. The maximum diameter of the first species is 33 mm., of the second 45 mm., and of the third 60–65 mm.

During the Merced epoch, following the San Pablo, the Scutellinæ reappear, represented by *Scutella interlineata*, Pl. XXII, fig. 6. This form shows considerable resemblance to *S. Gabbi* and has in common with it the supramarginal anus. *S. interlineata* differs from *S. Gabbi* in being much larger, in the position of the apical system, which is quite eccentric, and in the more pronounced supramarginal character of the anus. These differences are in the direction of greater specialization, except the position of the anus. This opening is travelling back from the lower surface toward the apical shield. Taking into consideration the points of relationship of these species, the fact that the differences may be due to specialization of the older form, and the order of occurrence of the two, it is probably safe to assume that *S. interlineata* is a modified descendant of *S. Gabbi*.

In the Quaternary deposits *Scutella* is replaced by an *Echinarachnius* which is a common form at the present time. This species, *E. excentricus*, Pl. XXII, fig. 8, is probably nearly related to *E. Gibbsi*, Pl. XXII, fig. 7, a form cited from the middle or later Tertiary. *E. Gibbsi* occurs near Buena Vista Lake, Kern County, in deposits which have been referred to the Miocene, and is also cited by Ashley from his transition beds between the Merced and the Miocene near Santa Cruz. This species much resembles the *excentricus*, but shows a greater degree of eccentricity of the apical system than is found in that species. The high degree of specialization in *E. Gibbsi* is not easily explained when we consider that it is the older form. As both forms are immigrants, and as their life-periods do not appear to overlap in this region, they are probably derived from a common stock, less specialized than either form, which lived in some other Pacific region during the middle Tertiary.

The table on the page opposite illustrates the occurrence and probable relationships of the known species of middle Californian sea-urchins. Unbroken lines connecting species indicate such structural and successional relationship as suggests descent. Dotted lines indicate doubtful descent or doubtful genetic relationship.

III. Description of Species.

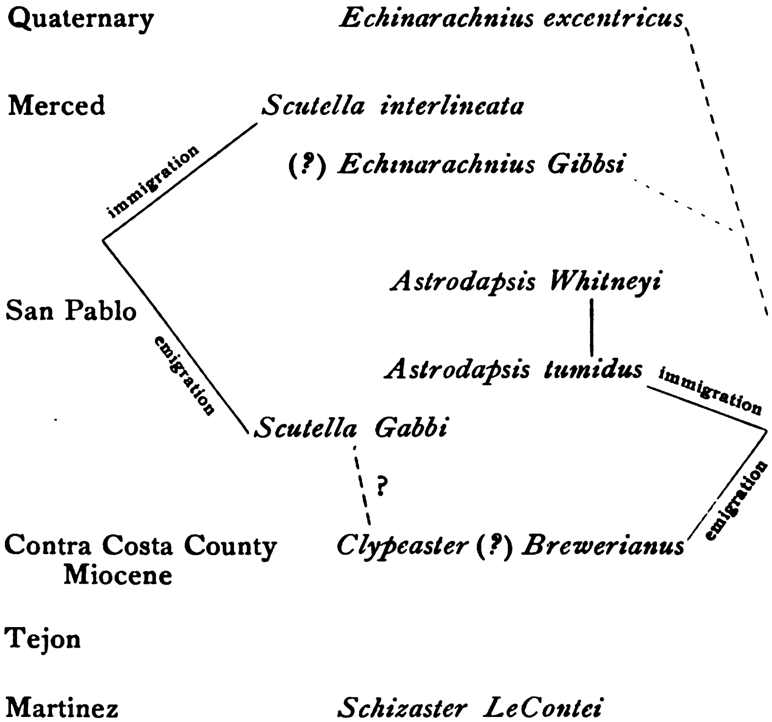
Genus Schizaster *Agassiz*.

Schizaster Le Contei, sp. nov.

Plate XXI, Figs. 1 and 1*a*.

Schizaster, sp., Journ. Geol., Vol. V, p. 773, Dec., 1897.

Small forms averaging a little less than 20 mm. in length. The largest specimen measured is about 23 mm. long. Test distinctly notched anteriorly by the groove of the anterior ambulacrum, truncated posteriorly; upper surface much elevated, with a sharp ridge running from the apical system to the posterior end, summit situated far back. Apical system eccentric, posterior, anterior to the summit.



Ambulacra broad, sunken; anterior laterals reaching a little more than half way to the margin; posterior laterals very short, less than half the length of the anterior pair, sometimes almost circular in outline. Ambulacral pores elongated, apparently yoked.

Mouth opening well forward, broad, two-lipped. Anus high up on the truncated posterior end.

Numerous large spines much like those of *Schizaster* have been found at one locality in the Martinez, but if they belong to this genus at all they were probably derived from another and much larger species. Tubercles larger on the actinal surface. Peripetalous fasciole quite distinct on one specimen. Traces of what appears to be the lateral fasciole have been seen beneath the anus.

Though crushed fragments of this species have been known to the writer for some years, the first recognizable specimens were discovered by the members of the class in palæontology, in April, 1897.

Not rare in the Martinez in Contra Costa County. Specimens preserved only as impressions or casts, usually badly crushed.

Genus **Clypeaster** *Lamarck.*

Clypeaster (?) Brewerianus *Rémond.*

PLATE XXI, FIG. 2.

Echniarachnius Brewerianus RÉMOND., Proc. Cal. Acad. Sci., Vol. III, 1863–67, p. 53.
Echinarachnius Brewerianus. Figured by GABB., Geol. Surv. Cal., Palæontology, Vol. II, 1869, p. 36., Pl. XII, figs. 65 and 65*a.*

Small forms averaging between 25 and 30 mm. in long diameter, the largest specimen measuriug about 35 mm. long. Test elliptical to circular, depressed, not markedly thin at the margins.

Ambulacra not standing in relief, broad, wide open at the ends, pores continuing to the margin. Inner row of rounded pores diverging gradually to the margin, drawing together only very slightly at about two-thirds of the distance. The outer pore rows at first diverge strongly but draw together again sharply at the point where the inner rows tend to converge. At this point they change their form from elongated to rounded and continue to the margin nearly parallel with the inner rows. The plates of the ambulacral areas increase slowly in size from the apical shield to the margin, the increase being most rapid at the point where the pore rows draw together. Near the margins the pores stand about half-way between the inner and outer ends of the plates.

Anus marginal to inframarginal. Tubercles nearly the same size on the upper and lower sides of the test.

Very few specimens have been obtained which show the lower surface, and the writer has been unable to determine the character of the ambulacral furrows. As this species is closely related to *Astrodapsis tumidus*, in which the furrows are clypeastroid, it is probable that they are much the same here and that the *Brewerianus* should be classed with, or near, *Clypeaster* rather than with *Echinarachnius*, as heretofore.

Common in the Contra Costa County Miocene.

Genus Astrodapsis *Conrad.*

Astrodapsis tumidus *Rémond.*

PLATE XXI, FIG. 3.

Astrodapsis tumidus RÉMOND., Proc. Cal. Acad. Sci., Vol. III, 1863–67, p. 52.
Astrodapsis tumidus. Figured by GABB., Geol. Surv. Cal., Palæontology, Vol. II, 1869, p. 37, Pl. XIII, figs. 68 and 68*a.*

Specimens ranging up to 45 mm. in diameter, average between 30 and 35 mm. Test circular to elliptical, depressed; margins, particularly in old individuals, inclined to be thickened and rounded, usually notched at the ends of the ambulacral areas.

Ambulacra always more or less elevated and showing, on perfectly preserved specimens, a faint groove running from the marginal notch more than half-way up to the apical system. Petals wide open at the ends, pores continuing almost to the margins. Inner rows of rounded pores only slightly convergent near the margin. Elongated pores of outer rows converging near the margin, becoming rounded and running parallel with the inner rows from that point.

Anus marginal or inframarginal. On well preserved specimens the inferior surface shows well marked, straight, undivided ambulacral grooves, which pass into the marginal notches and extend themselves on the upper surface, forming the median groove of the ambulacral areas. The tubercles are not noticeably different in size on the upper and lower surfaces.

The internal skeleton consists of a pair of strong, radially placed plates, extending half the distance from the margin to the center in each interambulacral space.

San Pablo formation, excepting the lowest beds.

Astrodapsis Whitneyi *Rémond.*

PLATE XXI, FIGS. 4 AND 4*a*.

Astrodapsis Whitneyi RÉMOND., Proc. Cal. Acad. Sci., Vol. III, 1863-67, p. 52.

Astrodapsis Whitneyi. Figured by GABB., Geol. Surv. Cal., Palæontology, Vol. II, 1869, p. 37, Pl. XIII, figs. 67 and 67*a*.

The average specimens of this species are considerably larger than those of *A. tumidus.* The largest specimen examined measured between 60 and 65 mm. in diameter. Test circular, strongly arched above; margin thin; marginal notches at the ends of the ambulacra deep.

Petals considerably elevated, with median groove running from the marginal notch toward the apex, pores similar in form and arrangement to those of *A. tumidus.*

Ambulacral furrows of the inferior surface well marked, straight, undivided. Anus inframarginal. Tubercles not differing materially on the upper and lower surfaces of the test, frequently smaller than in *tumidus.*

San Pablo formation, probably in the upper beds.

Genus Scutella *Lamarck.*

Scutella Gabbi *Rémond.*

Plate XXII, Figs. 5 and 5*a*.

Clypeaster Gabbi Rémond., Proc., Cal. Acad. Sci., Vol. III, 1863–67, p. 53.
Clypeaster Gabbi. Figured by Gabb., Geol. Surv. Cal., Palæontology, Vol. II, 1869, p. 36, Pl. XII, figs. 64 and 64*a*.

Test circular, much depressed, margin thin. Average specimens 25 to 30 mm. in diameter, largest specimens ranging up to 40 and 45 mm. in diameter.

Petals short, not extending more than two-thirds of the distance to the margin; excepting the anterior one, they are nearly closed at the ends. Anterior petal wide open. Excepting in the anterior area, the ambulacral plates suddenly enlarge and the area rapidly widens beyond the ends of the petals. In these areas, pairs of small, round pores, diverging strongly from the ends of the petals, may be present almost to the margins. In the anterior petal the plates do not enlarge as noticeably toward the margin as in the others, neither do the more persistent pore pairs diverge as much.

Apical shield with four genital pores, there being none at the end of the posterior interambulacral area. Anus marginal to supramarginal; in quite a number of specimens it is found to be entirely on the upper surface. No marked difference is noticeable between the tubercles of the upper and lower surfaces.

The ambulacral furrows of the actinal surface are not usually well preserved and have been clearly seen on only a few specimens; they divide dichotomously a little less than half-way to the margin.

San Pablo formation, in the lowest beds.

Scutella interlineata *Stimpson.*

Plate XXII, Fig. 6.

Scutella interlineata Stimpson, Pacific R. R. Rep., Vol. V, 1856, p. 153, Pl. IV, fig. 30.
Scutella interlineata. Redescribed by Rémond., Proc. Cal. Acad. Sci., Vol. III, 1863–67, p. 14.

Test pentagonal to circular, angular or truncated posteriorly, somewhat arched above; summit nearly central and in front of the eccentric apical system, specimens ranging up to over 120 mm. in diameter.

Ambulacra rather broad, of unequal length, anterior three of about the same length and longer than the posterior pair. Anterior petal open at the end, the others nearly closed. Few if any pores continuing beyond the ends of the petals.

The distance from the eccentric apical system to the posterior margin is to the distance to the anterior margin as 1 to 1.5. The anus is supramarginal, being separated from the margin in adult specimens by about the width of one of the marginal interambulacral plates.

No specimens have been seen by the writer in which the ambulacral furrows are well shown. On such specimens as show the lower side, the furrows seem to be dichotomously divided near the mouth. This agrees with Rémond's description, which also states that the furrows are not as well marked nor as much branched as in *Echinarachnius excentricus*.

The spines of the upper surface are about 1 mm. long; they are longitudinally striated and at the distal end are strongly swollen and obliquely truncated or bent. The spines of the lower surface are slender striated rods about 2 to 3 mm. long. The tubercles differ little in size on the upper and lower surfaces.

The internal skeleton comprises numerous irregular pillars and plates near the margin and a pair of radial plates in each interambulacral space.

Common in the Merced series.

Genus **Echinarachnius** *Leske.*

Echinarachnius Gibbsi *Rémond.*

PLATE XXII, FIG. 7.

Scutella Gibbsi RÉMOND, Proc. Cal. Acad. Sci., Vol. III, 1863–67, p. 13.
Scutella Gibbsi. Figured by GABB, Geol. Surv. Cal., Palæontology, Vol. II, 1869, p. 37, Pl. XII, figs. 66 and 66*a*.

Test quadrate-oval in outline. Upper surface well arched, summit behind the middle of the long diameter but in front of the very eccentric apical system. Specimens ranging up to 70 mm. in length.

Petals broad, open at the ends. Posterior laterals wide apart, ovate in outline, one-half the length of the anterior pair. Anterior petal longer than the anterior laterals; scattered pores continue some distance beyond the end.

The apical shield is very eccentric. In a specimen measuring 52 mm. in length, the distance from the apical shield to the posterior margin is to that to the anterior margin as 1 to 2.18; in a specimen 70 mm. long the ratio is 1 to 2.89. Four genital pores are present. The madreporic body is large and is pentagonal in outline. The anus is inframarginal.

The well marked ambulacral furrows are dichotomously branched near the mouth-opening and send off numerous secondary branches from these forks. The numerous tubercles of the upper surface are very small and are set in faint pits. On the lower surface the tubercles are fewer in number and larger, and stand in well defined pits.

From Neocene beds near Buena Vista Lake, Kern County, and listed by Ashley[1] from his transition beds near Santa Cruz.

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[1] Proc. Cal. Acad. Sci., 2d Ser., Vol. V, 1895, p. 328.

Echinarachnius excentricus *Eschscholtz*.

Plate XXII, Fig. 8.

Scutella excentrica Eschscholtz, Zool. Atl., Pl. XX, fig. 2, 1826.
Echinarachnius excentricus Valenciennes, Voyage Vénus, Pl. X, 1846.

Though a discussion of this species is perhaps not properly included in a treatise on Tertiary forms, its doubtful occurrence in the Pliocene is considered a warrant for its introduction. Moreover, the position the species occupies as the last of the Clypeastroids in this region makes desirable a comparison with the extinct forms. This is graphically done on Plate XXII, where *E. excentricus* appears with its nearest allies from this Coast.

From *E. Gibbsi* the *excentricus* differs in the less degree of eccentricity of the apical system and in the greater complexity and length of the ambulacral furrows. The distance of the apical shield from the posterior margin is to that from the anterior margin as 1 to 1.8+. The ambulacral furrows are split up into a great number of small branches, of which the strongest pass over the margins and extend over the upper surface. Four of the strongest furrows run to the lateral petals and stretch through their median areas almost to the apical system. Those furrows not passing to the petals sometimes reach half-way to the apical system.

Quaternary, possibly also in the later Pliocene. The fossil forms do not differ materially from those of the Recent period.

Palæontological Laboratory,
University of California,
Berkeley, California,
September, 1898.

EXPLANATION OF PLATE XXI.

All figures natural size.

Fig. 1. *Schizaster Le Contei*, sp. nov.
View of an obliquely crushed specimen from above.

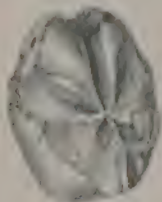
Fig. 1a. Lower surface of the specimen of *Schizaster Le Contei* shown in fig. 1.

Fig. 2. *Clypeaster* (?) *Brewerianus* RÉMOND.

Fig. 3. *Astrodapsis tumidus* RÉMOND.

Fig. 4. *Astrodapsis Whitneyi* RÉMOND.

Fig. 4a. Lower surface of the specimen of *Astrodapsis Whitneyi* shown in fig. 4.



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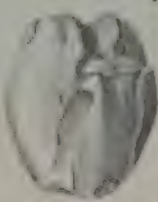

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2

3

4

4a

Fig. 1-1a Schizaster Le Contei, sp. nov.
Fig. 2 Scutella Breweriana, Rémond
Fig. 3 Astrodapsis tumidus, Rémond
Fig. 4-4a Astrodapsis Whitneyi, Rémond

EXPLANATION OF PLATE XXII.

All figures natural size.

Fig. 5. *Scutella Gabbi* RÉMOND.
Fig. 5*a*. *Scutella Gabbi* RÉMOND.
Showing form and arrangement of plates and pores.
Fig. 6. *Scutella interlineata* STIMPSON.
Fig. 7. *Echinarachnius Gibbsi* RÉMOND.
Fig. 8. *Echinarachnius excentricus* ESCHSCHOLTZ.

Fig. 5, 5a. Scutella Gabbi, Rémond.
Fig. 6. Scutella interlineata, Stimpson.
Fig. 7. Echinarachnius Gibbsi, Rémond.
Fig. 8. Echinarachnius excentricus, Esch.

PROCEEDINGS

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THIRD SERIES.

GEOLOGY. VOL. I, No. 6.

The Fauna of the Sooke Beds of Vancouver Island.

BY

JOHN C. MERRIAM.

WITH ONE PLATE.

Issued March 6, 1899.

SAN FRANCISCO:

PUBLISHED BY THE ACADEMY.

1899.

THE FAUNA OF THE SOOKE BEDS OF VANCOUVER ISLAND.

BY JOHN C. MERRIAM.

THE SOOKE beds, so named from their occurrence in the Sooke district, on the southern coast of Vancouver Island, have been principally studied in the field by Dr. C. F. Newcombe of Victoria, B. C., the fossil invertebrates collected by him being placed at the disposal of the writer for study and description. As the result of the investigation of this material, together with that from other horizons, the author has, during the past two years, published two diagnostic notes[1] on this fauna.

As no figures of the new species have been published, and as investigation of this fauna is not easily combined with any other to which the writer is at present giving particular attention, it was thought best to bring together in one note the principal facts known regarding the fauna, furnishing also figures of the new species. Future investigation will probably add many new forms to the list given in this paper.

The first mention of the Sooke beds made in the literature is by Mr. James Richardson,[2] who in 1876 noticed the occurrence of fossiliferous rocks in the Sooke district. The following extract from his paper expresses his opinion of the beds:—

"At the mouth of John's River the lowest beds are gray sandstone, in some places crowded with fossils belonging

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[1] "Note on Two Tertiary Faunas from the Rocks of the Southern Coast of Vancouver Island," Bull. Dep't Geol., Univ. Cal., Vol. II, No. 3, Dec., 1896.
"New Species of Tertiary Mollusca from Vancouver Island." Nautilus, Vol. XI, October, 1897, p. 64.

[2] Geol. Surv. Canada, Rept. Prog., 1876-77, pp. 160-192.

 March 4, 1899.

apparently to three or four species. These are referable to the genera *Ostrea*, *Pecten*, and *Saxidomus*, and are either of Tertiary or Post-Tertiary age."

In 1892 Dr. W. H. Dall[1] mentioned the occurrence of marine beds of Miocene age near Sooke.

Dr. Newcombe has, in 1893–98, made humerous visits to the outcroppings of the beds near Muir and Coal Creeks, bringing back a considerable amount of material in a very good state of preservation.

The cliffs in which the fossils occur are said by Dr. Newcombe to consist of soft sandstone and conglomerate. The strata do not appear to be greatly disturbed. Molluscan remains are found in abundance in both the sandstone and the conglomerate. In most instances the specimens are well preserved, showing the original unchanged material of the shell.

The number of known species being small, it is perhaps not possible to determine with absolute accuracy the age of this horizon. The recent and extinct species are, however, about evenly divided, so that both the Quaternary and the Eocene are beyond the range of possibility. Within the limits of the Neocene the nearly equal number of extinct and living forms points to Middle Neocene, while the general relationships of the fauna to the known Miocene and Pliocene faunas of the coast show no preponderance of affinity in either direction. The total evidence available seems then to indicate the Middle Neocene age of the Sooke fauna.

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[1] Bull. U. S. Geol. Surv., No. 84, p. 230.

TABLE ILLUSTRATING THE RELATIONSHIPS OF THE SOOKE FAUNA.	Recent.	Pliocene, Calif.	Miocene, Calif.	Astoria Miocene.[1]	Extinct.
1. *Placunanomia macroschisma* DESH......	*	*			
2. *Mytilus edulis* LINN....................	*	*	*	*	
3. *Cerithidea Californica* HALD............	*	*	*		
4. *Acmæa mitra* ESCH	*				
5. *Crepidula rugosa* NUTT. (*aff.*)...........	*				
6. *Pecten æquisulcatus* CARP. (*conf.*)........	*				
7. *Pecten hastatus* SOWB. (*conf.*)...........	*	*	*		
8. *Chrysodomus dirus* REEVE	*				
9. *Yoldia impressa* CON	*	*	*	*	
10. *Pectunculus patulus* CON..		*	*	*	*
11. *Trochita inornata* GABB.................			*	*	*
12. *Sinum scopulosum* CON. (*conf.*).........				*	*
13. *Cytherea* (?) *Newcombei* MERRIAM.......					*
14. *Cytherea Vancouverensis* MERRIAM......					*
15. *Patella geometrica* MERRIAM............					*
16. *Nassa Newcombei* MERRIAM.............					*
17. *Bullia buccinoides* MERRIAM............					*
18. *Fusus* sp. nov.........................					*
19. *Fusus* sp. nov.........................					*
20. *Bittium* sp. nov. (?)					*
21. *Crepidula* sp......					
22. *Ostrea* sp.............................					
23. *Cardium* sp...........................					
24. *Cerithidea* sp..........................					
25. *Tapes* (?) sp...........................					

[1] Referring to the fauna described by Conrad from Astoria and identified by the writer at Carmanah Point, Vancouver Isl. See Bull. Dep't Geol., Univ. Cal., Vol. II, No. 3, p. 102.

The following species which have previously been diagnosed by the writer are here redescribed and figured:

Genus Cytherea *Lamarck.*

Cytherea (?) Newcombei *Merriam.*

PLATE XXIII, FIGS. 1 AND 14.

Cytherea, sp. nov., Bull. Dep't Geol., Univ. Cal., Vol. II, No. 3, p. 106.
Cytherea Newcombei MERRIAM, Nautilus, Vol. XI, 1897, p. 64.

Shell subquadrate to oval, high, moderately thick, truncated anteriorly. Beaks not prominent. Lunule faintly marked. Surface ornamented with numerous, irregularly placed growth lines and ridges. On some well preserved specimens a large number of very faint, radial lines are visible. Length of large specimens 70 mm., breadth 55 mm. Hinge of right valve with three cardinal teeth and a short pit for the anterior lateral tooth of the opposite valve. This pit for the reception of the anterior lateral tooth is shallower and much shorter than in the following species.

Cytherea Vancouverensis *Merriam.*

PLATE XXIII, FIG. 2.

Cytherea, sp. nov., Bull. Dep't Geol., Univ. Cal., Vol. II, No. 3, p. 106.
Cytherea Vancouverensis MERRIAM, Nautilus, Vol. XI, 1897, p. 64.

Shell oval, narrowly rounded anteriorly. Beaks prominent. Lunule well marked. The somewhat weathered surface of the shells ornamented by numerous, irregularly-placed growth ridges. Length of type specimen 62 (?) mm., breadth 48 mm. Hinge of right valve with three cardinal teeth and a long, deep tooth-pit for the reception of the anterior lateral tooth of the left valve. Pit between the two anterior cardinal teeth of the right valve ordinarily narrower and deeper than in *C. Newcombei.*

Genus Patella *Linné.*

Patella geometrica *Merriam.*

PLATE XXIII, FIG. 4.

Patelloid, sp. nov., Bull. Dep't Geol., Univ. Cal., Vol. II, No. 3, p. 106.
Patella geometrica MERRIAM, Nautilus, Vol. XI, 1897, p. 65.

Shell large and heavy, up to 50 mm. or more in length, suborbicular. Apex elevated, well forward. Surface ornamented by about twenty broad, strong, radial ribs, which are much wider than the interspaces. Radial ribs crossed by numerous prominent, narrow, sometimes leafy, transverse ridges.

Genus **Nassa** *Martini.*

Nassa Newcombei *Merriam.*

PLATE XXIII, FIG. 3.

Nassa, sp. nov., Bull. Dep't Geol., Univ. Cal., Vol. II, No. 3, p. 106.
Nassa Newcombei MERRIAM, Nautilus. Vol. XI, 1897, p. 65.

Shell between 25 and 30 mm. in length. Whorls five, with a well marked shoulder, ornamented by numerous longitudinal and transverse ribs which give the middle portion of the whorls a tessellated appearance. The upper revolving rib, which forms the angle of the shoulder, is stronger than the others and is usually separated from them by a distinct groove. On the last whorl the transverse ribs (about 25) are dominant on the upper portion, excepting the shoulder, and are latticed by the less conspicuous revolving sculpture. On the lower portion of the whorl the transverse ribs disappear leaving the well defined revolving ribs uninterrupted.

Genus **Bullia** *Gray.*

Bullia buccinoides *Merriam.*

PLATE XXIII, FIG. 5.

Ancillaria, sp. nov., Bull. Dep't Geol., Univ. Cal., Vol. II, No. 3, p. 106.
Bullia buccinoides MERRIAM, Nautilus, Vol. XI, 1897, p. 65.

Shell ovate, whorls five. Spire short. Suture partially or entirely covered. Aperture with strong anterior notch. Outer lip thin, sharp; inner lip with broad callus. Length 25-30 mm.

PALÆONTOLOGICAL LABORATORY,
UNIVERSITY OF CALIFORNIA,
BERKELEY, CALIFORNIA,
September, 1898.

EXPLANATION OF PLATE XXIII.

All figures natural size.

Fig. 1. *Cytherea* (?) *Newcombei* MERRIAM.
Fig. 1*a*. Doubtful hinge of right valve of *Cytherea* (?) *Newcombei*.
Fig. 2. *Cytherea Vancouverensis* MERRIAM.
Fig. 3. *Nassa Newcombei* MERRIAM.
Fig. 4. *Patella geometrica* MERRIAM.
Fig. 5. *Bullia buccinoides* MERRIAM.

Fig. 1-1a Cytherea Newcombei Merriam. Fig. 2 Cytherea Vancouverensis Merriam. Fig. 3 Nassa Newcombei Merriam. Fig. 4 Patella geometrica Merriam. Fig. 5 Bullia buccinoides Merriam.

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The Development and Phylogeny of Placenticeras

BY

JAMES PERRIN SMITH

WITH FIVE PLATES

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THE DEVELOPMENT AND PHYLOGENY OF PLACENTICERAS.

BY JAMES PERRIN SMITH.

Stanford University, California.

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August 4, 1900.

INTRODUCTION.

THE interest of the paleontologist in embryology, and in ontogeny in general, lies wholly in the desire to know the origin and relationships of biologic groups. A scientific interpretation of ontogenic data in terms of phylogeny depends on the extent of preservation of the ancestral record in individual development. The broad statement has often been made that each animal gives in its own development an epitome of the history of its race. Because of the law of heredity, this statement would be true, and the record would be complete, if nothing had interfered with the normal course of things. But, in reality, so many secondary elements are introduced in development, that authorities are very much divided as to the value of ontogenic stages as records of race history.[1]

There can be no doubt that students of postembryonic stages have been inclined to claim too much for the law of tachygenesis, while, on the other hand, students of embryology have been inclined to discredit it almost entirely, and to lay little stress on ontogenic stages as a recapitulation of phylogeny. The reason for this disagreement is not far to seek; it lies in the field and in the methods of research of the two groups of morphologists.

Types of Development.—Leaving out of consideration the *Protozoa*, which come into being with the essential characteristics of the adults, there are, in the *Metazoa*, two types of development: (1) the *fœtal type*, in which development takes place in the egg, or in the body of the parent, and the young animal comes into the world in form closely resembling the adult; (2) the *larval type*, in which the young animal comes out at an earlier stage of development, and reaches maturity only after considerable metamorphosis.

Secondary elements will be introduced in either type of development, and those variations that are favorable to the

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[1] In the preparation of this Introduction the writer has drawn largely on Balfour's "Treatise on Comparative Embryology," and on Lang's "Comparative Anatomy."

preservation of the species are likely to be perpetuated by heredity. Now in the fœtal type the most favorable variation consists in abbreviation, thus simplifying the development. Any characters that are useful in a free state, but not in a fœtal state, are liable to be lost. Thus in the fœtal type the tendency is towards loss of the record through omission of stages or obscuring them, for many organs that would be highly developed in mature forms, or in free larvæ, will be either suppressed or undifferentiated.

The vertebrates, most of the higher crustaceans, most land and fresh-water molluscs[1] have the fœtal type of development; and these embrace by far the larger part of animals whose ontogeny has been studied. It is not to be wondered at, then, that morphologists who deal exclusively with embryonic stages of these groups should be sceptical about the repetition of family history in individual development. Here many stages are omitted, and the rest so obscured and undifferentiated as to be unintelligible; and secondary characters, due to life in the egg or in the parent, are introduced, effacing what little meaning was left. Then, too, embryologists are often content to trace the animal but a little way toward perfection of development; they study the embryo until the cells begin to divide into groups indicating a beginning of organs, and call this studying ontogeny, when they have stopped before it could be told whether the animal was going to develop into fish, flesh, or fowl. To this sort of study is due the idea of "falsification of the record," a crime of which nature has not yet been guilty, although she at times may not, perhaps, have told the whole truth.

Primary and Secondary Larvæ.—If the way of the embryologist lies in stony places, that of the student of post-embryonic stages is not much smoother; formidable obstacles meet him on every side, reducing his small stock of faith. At the very outset he is confronted by the difficulty that there are two distinct types of larvæ: *(a) primary*

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[1] *Dreissensia*, a fresh-water pelecypod, which in very recent geologic time has immigrated from salt-water, still goes through its larval development, like its marine relatives.

larvæ, such as are more or less modified from ancestral forms, and have continued to develop as free larvæ since the time when they constituted the adult forms; *(b) secondary larvæ*, such as have been introduced by kenogenesis into the ontogeny of species that formerly developed by the fœtal process. If ancestral characters have been retained in the egg, then these secondary larvæ may bear some palingenetic characters, and thus be hard to distinguish from primary larvæ; otherwise they will be entirely adaptive, or kenogenetic. A case in point is the development of most insects, whose larval stages are supposed to be entirely secondary. Study of individual development in a group of this sort can throw no light on phylogeny.

The student of larval stages must confine himself to the primary sort, if he would correlate them with ancestral genera. The development of the cœlenterates, echinoderms, brachiopods, most molluscs, and the lower crustaceans is direct; thus larval stages of these groups may be bearers, to a greater or less degree, of ancestral characters. But since the free larvæ of even these groups are exposed to natural selection, secondary or kenogenetic characters will be introduced, obscuring the resemblance to ancestral forms; also characters that in the adult ancestral form were functional and fully developed may in the representative larval stage of the descendant be so little differentiated as to be unrecognizable.

But how can the morphologist who deals entirely with living species know whether a character is primary, and repeated by palingenesis in the larval history of the descendant, or whether it is secondary, and introduced by kenogenesis into that history? The answer to this lies wholly within the domain of paleontology, for only by finding a stage of growth represented by an ancestral form can the morphologist know that the characters of that stage are ancestral, and not secondary. Larval stages which may be the bearers of ancestral characters must then be compared with the adults of their predecessors, and the paleontologic record must be invoked as a final resort—the court from which there is no appeal.

And this was exactly the method used by Louis Agassiz, who first applied the law of acceleration of development to the study of systematic zoology, although it never had much influence on biologic investigation until the paleontologic studies of Hyatt (1872) in the invertebrates, and Cope in the vertebrates placed the law on a sound basis. It was reserved for Alpheus Hyatt (1866) to formulate the law, and to strengthen theory with practical examples based on study of Cephalopoda. In his later papers Professor Hyatt (1889, preface, p. ix) has given a more exact and comprehensive definition of the law of acceleration or *tachygenesis:* "All modifications and variations in progressive series tend to appear first in the adolescent or adult stages of growth, and then to be inherited in successive descendants at earlier and earlier stages according to the law of acceleration, until they either become embryonic, or are crowded out of the organization, and replaced in the development by characteristics of later origin." A still more definite statement by the same author (Hyatt, 1894) is the following: "The substages of development in ontogeny are the bearers of distal ancestral characters in inverse proportion and of proximal ancestral characters in direct proportion to their removal in time and position from the protoconch or last embryonic stage."

To insure trustworthy results in verifying this law, the investigator must have groups in which the larvæ are primary and reproduce ancestral characters; in which the living and the fossil are classified on the same basis; of which we have preserved a nearly complete geologic record; and of which material is available for the study of fossil ontogeny as a check on the living. Such groups are especially represented among the *Cœlenterata*, the *Echinodermata*, the *Brachiopoda*, and the *Pelecypoda* and *Cephalopoda* among the molluscs.

Unequal Acceleration.—Now, when the morphologist has settled the fact that primary larval stages do actually reproduce, more or less vaguely, characters that existed in the adult forefathers of the generation he is at work on, his troubles are even then not yet ended; for the characters do

not necessarily appear in the ontogeny of the descendant in the same association in which they occurred in the ancestor. A character useful to the immature form will have a tendency to be inherited at an earlier age than those useful only to the adult, and so by unequal acceleration of development the parallel between ontogeny and phylogeny is broken. It was once thought that the *Nauplius* larva of the crustaceans was a mature genus, then it was thought to be a larval representative of the extinct radicle of the Crustacea; later still, many morphologists have concluded that the *Nauplius*, while it bears many crustacean characters, still retains too many annelid characters to represent the radicle of the group; it is a typical crustacean larva, but not a representative of the primitive crustacean, and the two sets of characters are thrown together by unequal acceleration. Beecher (1895, p. 173, Pl. IX, figs. 1, 2, 4) has shown the same thing in the spiny larvæ of *Acidaspis* and *Arges*, where in the protaspis of these genera the spines characteristic of the adults appear, contrary to usage among the trilobites, in which larval stages are usually smooth. Thus before these animals have assumed characters that would identify them undoubtedly with trilobites they have assumed those most characteristic of their own genera. Jackson (1890, p. 381) has shown that in the larvæ of the *Pectinidæ* unequal acceleration may associate characters that were not synchronous in race history. F. Bernard (1896–97) has recently shown that the prodissoconch of pelecypods is sometimes striated and ribbed, characters that could not have belonged to the primitive pelecypod.

If unequal acceleration causes confusion in the phylembryonic stages, the difficulty is much greater in the larval and adolescent periods, where the shortness of the time of development causes throwing together of characters that were not contemporaneous in the ancestors, and where the small size and general habits prevent differentiation of organs that in the correlative adult forms were highly developed, thus obscuring and even destroying the exactness of the parallelism.

The two species of *Placenticeras*, of which the ontogeny is described in this paper, must have descended not only from the same perisphinctoid family, but also from the same species of *Hoplites;* and thus if the parallel were at all exact, they should be alike in the late adolescent stages, when they begin to show their generic characters. This, however, is not the case, for they are quite different throughout the cosmoceran stage, and back almost to the end of the larval period, where the transition from goniatite to ammonite took place. If this were interpreted without taking account of unequal acceleration, it would seem that the differentiation of the two species took place back in the Trias, and that different ægoceran forms were the remote ancestors of the two species, which we know could not have been the case.

The writer (1899) has recently worked out the ontogeny of two very nearly related species of *Schlœnbachia*, one of which, in its larval period, reproduces very exactly a *Paralegoceras* stage, while the other does not; the latter species has, however, all the paralegoceran characters, but associated with others that this genus never had, but which belonged to later descendants of this genus. There can be here no question of the veracity of nature in keeping the record, the difficulty lies in deciphering it. So it is not to be expected that any one species would give in plain terms the complete phylogeny of a genus, for stages that are plainly differentiated in one will be obscured in another, and only by studying the ontogeny of a number of species of one genus can the morphologist hope to get a complete history.

Retardation.—Another factor that makes it difficult to correlate ontogeny and phylogeny is *retardation* of development. Cope first recognized the principle, but in his writings confused it with unequal acceleration, and since his reasoning was purely theoretical the idea has never gained much foothold in biologic philosophy. Cope's statement (1887, p. 142) of the theory is as follows: "The acceleration in the assumption of a character, progressing more rapidly than the same in another character, must soon produce, in a type

whose stages were once the exact parallel of a permanent lower form, the condition of inexact parallelism. As all the more comprehensive groups present this relation to each other, we are compelled to believe that *acceleration* has been the principle of their successive evolution during the long ages of geologic time. Each type has, however, its day of supremacy and perfection of organism, and a retrogression in these respects has succeeded. This has, no doubt, followed a law the reverse of acceleration, which has been called *retardation*. By the increasing slowness of the growth of the individuals of a genus, and later and later assumption of the characters of the latter, they would be successively lost." This statement of Cope might apply equally well to unequal acceleration of characters, but in another part of this same work he gives a clearer statement: "Where characters which appear latest in embryonic history are lost, we have simple retardation, that is, the animal in successive generations fails to grow up to the highest point of completion, falling further and further back, thus presenting an increasingly slower growth in the special direction in question." (Cope, 1887, p. 13.)

These remarks of Cope were based on abstract reasoning, but it is possible to bring up some striking cases in support of the theory, notably among the brachiopods. Fischer and Oehlert (1892) have shown that while brachiopods go through many metamorphoses in individual evolution, and while each species is usually constant in the stages it goes through, it often happens that the individual is arrested in development, never reaching the full generic development of the mature stage. The individual then begins to reproduce its kind before maturity is reached, and tends to give rise to a stock that never reaches the full generic evolution of its ancestors. Dr. C. E. Beecher (1893*b*) has well described this: "In each line of progression in the Terebratellidæ the acceleration of the period of reproduction, by influence of environment, threw off genera which did not go through the complete series of metamorphoses, but are otherwise fully adult, and even may show reversional tendencies due to old age; so that nearly

every stage passed through by the higher genera has a fixed representative in a lower genus. Moreover, the lower genera are not merely equivalent to, or in exact parallelism with, the early stages of the higher, but they express a permanent type of structure, so far as these genera are concerned, and after reaching maturity do not show a tendency to attain higher phases of development, but thicken the shell and cardinal process, absorb the deltidial plates, and exhibit all the evidences of senility."

If, then, the morphologist tries to study the race history in one of these species thus arrested in development, he can not read the whole story, for the individual ontogeny will not recapitulate the higher stages lost by retardation.

Another remarkable case is that of the so-called "ceratites" of the Cretaceous. While there have been no goniatites since the Paleozoic, and no ceratites since the Trias, there are found among the ammonites of the Cretaceous some with septa of simple goniatitic character, and others with septa like those of the genuine ceratites. Now since the line of descent is broken and there is no possibility for a continuous line of these ancient primitive forms to have bridged over the great gap from the Trias to the Upper Cretaceous, we must explain this either by reversion, or in some other way. But it is not a simple case of reversion, for, as has been pointed out by several writers (Douvillé, 1890, pp. 275–292; Nicklès, 1890), the septum of adolescent ammonites of this group is not more complex, but really less so, than that of adults, although they are derived from Jurassic genera with complex septa. Thus Douvillé, in the paper cited above, derives the group *Placenticeras-Sphenodiscus* from *Hoplites;* the Pulchellidæ, composed of *Pulchellia*, *Neolobites*, and *Tissotia*, he derives from *Oppelia* of the Jura. Since in each case the ancestral forms are more complex than the descendants, the reduction in complexity of generic evolution can be explained only by retardation, or arrested development. F. Bernard (1895, p. 668) has, in addition, pointed out the fact that the adult of *Pulchellia* is like the adolescent stage of the ancestral *Oppelia*. Now, if

we define the law of acceleration of development to mean that in a progressive series the young of the descendants correspond to the adults of their more remote ancestors, we find that this does not apply to a retrogressive (retarded) series. In this latter case we must restate the law as follows: The adults of descendants correspond to the young of their more remote ancestors, the higher generic stages to which these ancestors attained having been dropped away by successive retardation, or arrested development. The retarded series themselves may become the radicles of new stocks, and so we may have cases where the ontogeny of any one species or genus can never give the full history of the race.

Groups Available for Correlation.—We see, then, that the student of morphogeny of animals has to be on his guard, first against the loss of generic stages during the period while the animal is in the egg; then against the introduction of secondary larval stages when the ancestors lacked them; then against the introduction of secondary characters due to adaptation; then against unequal acceleration, bringing together, in the ontogeny of the descendant, characters that occurred in separate generations of ancestors; and lastly, against retardation, by which the form never reaches the full generic evolution of its ancestors, and where, if a new series starts out from the retarded form, the complete family history is not recorded in ontogeny.

Is it to be wondered at, then, that the student of morphology becomes a sceptic, or even a rank unbeliever with regard to the value of ontogenic stages as records of history? It is only to be expected that the biologist, especially one that deals almost exclusively with living species, should be inclined to discredit the law of tachygenesis, and to believe that there is such an inextricable muddle of omissions, secondarily introduced characters, and unequal acceleration of those actually repeated, that the record is wholly untrustworthy, or at least illegible. And yet there are so many species and genera in the various groups of invertebrates whose ontogeny is simple, progressive and fairly

complete, and whose stages of growth are almost exact repetitions of successive antecedent genera, that it would be impossible to find a student of the morphogeny of the brachiopods, the marine molluscs, or the lower crustaceans, that does not believe implicitly in the value of larval stages of these groups as records of their family history. And this is especially true of the paleobiologists, who regard it of little importance whether the animal under investigation died yesterday, during the Flood, or during the Paleozoic era, whether it is preserved in alcohol or in a more permanent museum in the bosom of Mother Earth; they recognize the fact that the laws that govern the rise and decline of organisms were just as true then as now, and that the life-history of a Cambrian trilobite has as much bearing on modern biology as does the history of the living cray-fish.

Not all groups are equally useful to the student of morphogeny, but in each of the lower subkingdoms there are genera of which the ontogeny has been worked out and correlated in no uncertain terms with the history of the race. The testimony of these various groups is so uniform, notwithstanding the fact of its having been gathered by men of different beliefs, that its value can not be doubted. It is also noteworthy that in the higher groups, such as cephalopods and crustaceans, the evidence and the correlations are much more decided.

Cœlenterata.—It has been shown by Dr. C. E. Beecher (1891) that the young stages of the Favositidæ correspond to *Aulopora*, or to some other similar unspecialized genus. This same conclusion has been reached by Dr. G. H. Girty (1895) based on a study of the ontogeny of *Favosites*, *Syringopora*, and other tabulate corals, all of which are shown to go through an *Aulopora* stage of growth.

Echinodermata.—The only crinoid of which the ontogeny is known is *Antedon*, which has been shown by Sir Wyville Thomson (1865) to go through successively stages corresponding to the *Ichthyocrinoidea* of the Paleozoic, and *Pentacrinus* of the Mesozoic, before it becomes free swimming and takes on the characters of *Antedon*.

Dr. R. T. Jackson (1895) has been able to prove even in the Paleozoic sea-urchins the possibility of correlating growth stages with phylogeny, in spite of the great difficulties due to resorption of plates, and change of form.

Brachiopoda.—According to Beecher (1891, 1892) all brachiopods go through a primitive protegulum stage, correlative with the supposed ancestor of the class, although *Paterina*, which was formerly supposed to be this radicle, has been shown to be much more highly specialized than the protegulum stage. The later stages of growth of this class are capable of even more remarkable correlation, as has been shown by Beecher (1893*a*) in a number of papers, where every stage of growth is distinctly homologous with well known pre-existing genera; and these same successive genera show a gradual transition in the adults.

Even among the Paleozoic spire-bearers (*Helicopegmata*), this holds good, for Beecher and Schuchert (1893) have demonstrated that the early stages of this group are homologous with the terebratuloids (*Ancylobrachia*), and more especially with the Paleozoic genus *Centronella*, the most primitive of the loop-bearing brachiopods.

Mollusca.—Jackson's correlations of the stages of growth of pelecypods (1890) with their race history have already become classic; according to these, every pelecypod begins its bivalve state with a nuculoid stage, homologous with the primitive radicle of the group. Every *Pecten* goes through stages successively correlative with a nuculoid, *Rhombopteria*, *Pterinopecten* and *Aviculopecten*, before it reaches maturity, each stage appearing in the order of the ancestral genus. Even the greatly modified oyster shows its kinship with this group by its nuculoid and *Rhombopteria* stages.

The researches of Branco have made it clear that each group of cephalopods has its typical phylembryo, in a general way correlative with the radicle of the group, and that the later stages may be compared very accurately with ancestral families and genera. The way for this was opened by Hyatt's memoirs on the ontogeny of the ammonites, in which it was shown that in each perfect adult ammonite shell the complete individual ontogeny is recorded. By

using this same method Karpinsky (1889) has been able to correlate the ontogeny of *Medlicottia* and *Pronorites* with successive ancestral forms, from *Anarcestes*, *Ibergiceras*, *Paraprolecanites*, up to the adult stage.

By the ontogenic method Buckman has been able to get at a sound basis of classification of the Jurassic ammonites, and to correlate the growth stages of many of these with their race history. Although his conclusions as to the systematic position of many of these genera do not agree with the ideas commonly accepted concerning them, it must not be forgotten that these conclusions are based, not merely on ontogenic study alone, but also on the gradual transitions of a series of adults. This is the strongest confirmation that any phylogenic research could ever have.

Crustacea.—Among the most convincing morphogenic researches are Beecher's studies (1895) in the ontogeny of the trilobites, all of which are shown to go through a phylembryonic *protaspis* stage, correlative with the primitive crustacean, and similar to the protonauplius of the less specialized living crustaceans. Here, too, it was demonstrated that the larval and adolescent stages of Devonian, Silurian, and even Cambrian trilobites may be correlated with the adults of pre-existing genera, giving the basis of a natural, or biogenetic, classification of this extinct group.

Many more cases might be added to those cited here, but surely no additional evidence is needed, for all this points in the same direction, whether gathered by believers in or by opponents of the theory of evolution. To this latter class belongs the evidence brought forward by Barrande (1852) in the ontogeny of trilobites, and by Agassiz in the law of recapitulation or acceleration of development. Each of these naturalists used unhesitatingly the method that in the hands of Hyatt and his followers has been so fruitful of results.

AFFINITIES OF PLACENTICERAS AND HOPLITES.

The genus *Placenticeras* was established by F. B. Meek (1876) to include large, discoidal, compressed shells, with narrow umbilicus, narrow, flattened abdomen, and rows of

knots forming a pair of marginal keels on the abdomen; shell with obscure knots or ribs, but with fine sigmoid lines of growth; septa divided into a large number of lateral lobes and saddles, increasing in size up to the third, and decreasing from that toward the umbilicus. The type of the genus was *Placenticeras placenta* Dekay, of the Fort Pierre group, Upper Cretaceous. Along with the type species Meek included in this group also *P. andoorense* Stoliczka, *P. guadaloupæ* Roemer, and *P. orbignyanum* Geinitz, all from the Cretaceous. Meek did not attempt to place *Placenticeras* in any of the so-called families of ammonites, but by almost universal consent paleontologists have grouped it with the Amaltheidæ (Zittel, 1885, p. 452; 1895, p. 407; Steinmann, 1890, p. 416), along with the so-called "Ceratites" of the Cretaceous, on account of a certain resemblance to the Jurassic forms with beaded abdominal keels. This, however, was before the days when paleontologists looked upon the development of ammonites as the key to their systematic position, and taxonomy made little pretense of being biogenetic.

The first dissenting voice was raised by H. Douvillé, in a paper "Classification des Cératites de la Craie" (1890), where the opinion was expressed that *Placenticeras* and *Sphenodiscus* both developed out of the group of *Hoplites-Sonneratia*. F. Bernard (1895, p. 676) has accepted this view, placing the genus under the Stephanoceratidæ. Unpublished researches of the writer show, however, that *Sonneratia* and *Desmoceras* are much more closely allied to *Stephanoceras* than is *Hoplites*, from which group *Placenticeras* originated. *Hoplites* is considered by the writer, not as originating from the Stephanoceratidæ, but as having a common origin with that family in the Ægoceratidæ.

The species from the Lower Cretaceous commonly assigned to *Placenticeras* mostly belong to *Oppelia*, to *Sphenodiscus*, and to other genera. Not every keeled, discoidal ammonite can be placed here, for it is well known that among the ammonites mere resemblance is not proof of near kinship. Sarasin (1893) has shown that *Ammonites*

nisus d'Orb. belongs to *Oppelia*, and that there are several series of these plate-shaped ammonites, commonly ascribed to the Amaltheidæ, but in reality derived from wholly different groups.

The true species of *Placenticeras*, that is of the type of *P. placenta*, are descendants of *Hoplites*, and thus have no kinship with the Amaltheidæ; this is the opinion of H. Douvillé, and it has been fully confirmed by an ontogenic study of two species. These species had been under investigation by the writer for a long time before their real affinities were found out; the largest specimens obtained were between 20 and 30 millimetres in diameter, and were naturally supposed to be adults, for on the last coil there was no further progressive development. One species was remarkably like *Hoplites dufrenoyi*, and the other like *H. splendens*, both of the Gault; thus they were assigned to *Hoplites*, although the premonition of *Placenticeras* was shown in the provisional name, "*H. placenticeratoides*," given by the writer, and in the unpublished description, in which it was said that this species was tending decidedly toward becoming a *Placenticeras*, although it had not yet quite developed beyond the limits of *Hoplites*. After this was written, although luckily not published, the writer obtained a number of larger specimens of both species, up to 170 millimetres in diameter, showing a perfect and gradual transition between the two genera.

The earliest known species of *Placenticeras* occur along with *Sphenodiscus* in the zone of *Mortoniceras rostratum* (=*Schloenbachia inflata*), in the Albian stage, upper Gault, top of the Lower Cretaceous. Thus the genus must have developed out of *Hoplites* in the upper part of the Lower Cretaceous. Now since the origin and affinities of *Hoplites* are pretty well known, a discussion of this genus becomes of prime importance in an investigation of the derivation and systematic position of *Placenticeras*.

The genus *Hoplites* was established by Neumayr (1875) to include forms with rather compressed flattened sides, high whorls, moderately narrow umbilici, sinuous lateral ribs with umbilical and marginal knots or spines, and usually

with a furrow interrupting these ribs on the abdomen, often forming a pair of shoulder keels. The septum is finely and deeply divided; in addition to the first and second lateral lobes there are one or more auxiliary lobes, and the two lateral saddles are deeply divided by secondary lobes.

This genus, which Neumayr supposed to have originated from *Perisphinctes*, included many species that have since been placed in other genera, in some cases even in other families, but after the segregation from it of *Sonneratia* Bayle, *Stoliczkaia* Neumayr, *Pulchellia* Uhlig, there is still left a large number of species, showing great variation in form and other characters, which may, after all, not belong to a monophyletic genus. Zittel (1885, p. 475; 1895, p. 428) first classed *Hoplites* with the Stephanoceratidæ; then in a later work, with the Cosmoceratidæ, along with *Cosmoceras* Waagen, *Parkinsonia* Bayle, *Sonneratia* Bayle, and *Acanthoceras* Neumayr, as a side branch from the Stephanoceratidæ. Zittel is inclined to the belief that *Cosmoceras* is the direct ancestor of *Hoplites*, an opinion which seems to be the more correct, for the two species of *Placenticeras*, of which the ontogeny is described in this paper, show a decided *Cosmoceras* stage in the adolescent period just before the *Hoplites* stage, and one of them retains some of these characters until maturity. In each case this stage begins by a sudden stopping of the perisphinctoid ribs on the abdomen, the formation of strong knots on the angular abdominal shoulders, and a sharper forward bending of the lateral ribs, which fork near the shoulders, forming the beginning of a second row of knots. At this stage one can see a resemblance, not to the exaggerated species of *Cosmoceras*, such as *C. ornatum*, *C. jason*, or *C. elizabethæ*, but rather to some simpler form; it is not possible to refer to any particular species as the ancestral form, nor is it likely that any one species was the only one that developed the style of rough ornamentation that is called *Hoplites*.

F. Bernard (1895, p. 673) agrees substantially with Zittel as to the systematic position of the genus, as do also most other writers on the subject; Steinmann (1890, p. 445) groups it

in the Ægoceratidæ, subfamily Perisphinctinæ, division *(b)* Tuberculati, along with *Acanthoceras* and *Holcodiscus*. All these writers connect the genus with *Psiloceras* as the radicle from which the entire perisphinctoid stock sprang, although the opinion is based, not on ontogenic study, but purely on the geologic succession of types, a satisfactory method only where the paleontologic record is very complete.

In a later paper Sarasin (1897) concludes, as a result of ontogenic study, that *Hoplites* is not a member of the highly specialized Stephanoceratidæ, but comes from the more primitive perisphinctoids along with *Desmoceras*. Most writers agree that the perisphinctoids come from the Ægoceratidæ, that they, in turn, are derived from *Psiloceras*, and that this genus branched off from the Phylloceratidæ. E. Haug (1894) expresses the opinion that not only the Ægoceratidæ, but also the Amaltheidæ, the Arietidæ, and most of the other Jurassic stocks were derived from the Phylloceratidæ, because their septa are triænidian in early youth, and megaphyllian in the development of the principle saddles. This seems to be nearer the mark, although the descent must be from some of the earlier unspecialized forms of the Phylloceratidæ, such as possibly *Monophyllites*, although certainly not from any known species of that genus; at any rate, none of these genera show a *Psiloceras* stage in their ontogeny. S. S. Buckman (1898, p. 445), contrary to the general opinion, says that *Psiloceras* is not the ancestor of the Arietidæ nor the Ægoceratidæ, but is, itself, a degenerate form.

The immediate ancestors of the Ægoceratidæ may be sought among the Polymorphidæ, a group established by E. Haug (1887) to include a number of the more primitive ammonites of the Lias. *Agassizceras*, the principal genus of the group, is considered by Hyatt (1889) to be the immediate ancestor of the agassizceran branch of the Arietidæ, and the direct descendant of *Psiloceras*. Neumayr (1878) segregated a number of the simpler species of this group under the name of *Cymbites*, characterized by rather globose form, very slightly ammonitic septa, and absence of

ventral keel. Hyatt (1889) says *Cymbites* is probably only the young of *Agassizceras*, while Haug considers the characters upon which Neumayr based the genus not to be sufficiently constant to warrant the separation, although he regards the problematic species as adult forms. However this may be, we know that the young of the more specialized Polymorphidæ are like *Cymbites*, and whether the forms described by Neumayr were adults or not, there must have been such a genus as ancestor of the group, and not only of this small section, but also of the Ægoceratidæ as well; so it will be well to retain *Cymbites*, although Buckman leaves this genus out of the Polymorphidæ, which he does not consider the primitive family.

Another form that may possibly be in the genetic series of the Ægoceratidæ, and thus of *Placenticeras*, is the genus *Diaphorites* Fucini (1896, *a* and *b*, p. 232, Pl. XXV, figs. 1–15), which, although small, is surely made up of adult forms. This genus greatly resembles *Cymbites*, and is thought by Fucini to be genetically connected with the Phylloceratidæ; the youthful stages of *Diaphorites vetulonius* Fucini, as described and figured by that author, are remarkably like the young of *Placenticeras pacificum*, sp. nov., figs. 13 and 14 of Fucini's paper, reproducing exactly the glyphioceran stage, and fig. 12 is like the *Nannites* stage of *Placenticeras*. The early adult septa of *Diaphorites*, copied on plate XXVIII, fig. 7, after Fucini, are almost exactly like the early adolescent septa of *Placenticeras*, and the parallel is also quite exact as to form and sculpture. As only one species of the genus is known as yet, and that only in Italy, it would be premature to single this out as the connecting link between the perisphinctoid group, and the phylloceran stock; the most we can say is that this connecting link must have been some such genus.

Fucini (1896, *a* p. 124, and *b* p. 236, Pl. XXV, figs. 16–21) has described another genus, *Pimelites*, that might possibly be the radicle of the ægoceran stock; it is very like *Diaphorites*, differing only in some unimportant characters, and being, in Fucini's opinion, intimately related to the

Phylloceratidæ, and regarded as a possible ancestor of *Cœloceras*, *Sphæroceras*, and *Stephanoceras*. Until the ontogeny of the genus is worked out, opinions on its phylogeny can not be much more than speculations.

The more remote derivation of the Ægoceratidæ is still more uncertain; Hyatt and nearly all other paleontologists regard *Psiloceras* as the radicle of the group, while many derive *Psiloceras* from the Phylloceratidæ, the development and phylogeny of which group have been very fully discussed by the writer in a recent paper (1898). In his opinion the ammonite radicle of this group is to be sought in *Nannites*, or in some Permian or Triassic genus of that transitional character. No attempt was made to trace the genealogy back into the goniatites, further than to indicate the probability that the remote radicle would be found among the Prolecanitidæ. The ontogeny of *Nannites* is still wholly unknown, but the writer has recently worked out the development of an undescribed genus, associated with, and evidently very closely related to *Nannites*, with larval and adolescent stages showing unmistakable glyphioceran affinities. F. Bernard (1895, p. 656) derives the Phylloceratidæ from *Popanoceras*, which is most improbable, in view of the evident derivation of that genus from the primitive Arcestidæ. E. Haug (1898, p. 45) traces the Phylloceratidæ through *Monophyllites* back to *Nomismoceras* and *Gephyroceras* of the phylum Gephyroceratidæ; although, as shown by the writer, the young stages of both *Phylloceras* and *Lytoceras* show an unmistakable resemblance to *Glyphioceras*; the ontogeny of *Nomismoceras* is unknown, so any attempt at present to trace its origin must be largely speculative; it may, however, have come from *Glyphioceras*.

Whatever the goniatite radicle of this group may have been, the secondary radicle of *Hoplites*, *Desmoceras*, *Ægoceras*, *Perisphinctes*, and *Cœloceras* was the same for all. The young stages of *Hoplites*, as figured by Branco (1879, Pl. XIII, fig. 2, *a–m*), resemble the young of Perisphinctes (Branco, 1879, Pl. XIII, figs, 1, *a–l*), while both resemble the larval and early adolescent stages of *Cœloceras*, as illustrated on Plate XII of Branco's memoir, and of *Desmoceras*

(Puzosia), on Plate XI, fig. 5, *a–k*. On Plate XIII, fig. 5, *a–n*, Branco has figured the early stages of *Cymbites*, which show all the essential characters observed in the larvæ of the other genera mentioned, although less accelerated, and necessarily more primitive.

The systematic position of *Hoplites*, according to the investigations of the writer, and of Sarasin (with whom the writer substantially agrees), is not with the Stephanoceratidæ, but with the Perisphinctinæ. *Desmoceras*, on the other hand, undoubtedly belongs to the Stephanoceratidæ, along with *Sonneratia*, for adolescent stages of both genera resemble perfectly *Stephanoceras*[1] and *Holcostephanus*, and these, in turn, sprang from *Cœloceras*. The ægoceran ancestor of *Cœloceras* and of the perisphinctoid group is the same, and can be traced back to a *Cymbites*-like form, and this must have originated in a genus with the essential characters of *Nannites*, with the possible intermedium of some primitive unknown member of the Phylloceratidæ. The immediate ancestor of *Hoplites* is not to be sought in a perfected *Cosmoceras*, nor did this genus spring from any highly specialized *Perisphinctes*, which, according to Buckman, is a degenerate group of the Stephanoceratidæ; nor was any fully differentiated ægoceran form the parent of this perisphinctoid ancestor. We must rather seek, in each case, the radicle in the primitive, unspecialized beginnings of each group. And if all these genera come from a phylloceran stock, they certainly do not come from *Psiloceras*, *Phylloceras*, nor *Lytoceras*, but from some primitive member of the Phylloceratidæ, as yet unknown, or at least not recognized as belonging to that group. At any rate, the stage between that resembling *Nannites*, and that suggesting *Cymbites*, is too short, and too little differentiated in any species of *Hoplites* yet investigated for a probable reference to *Monophyllites*.

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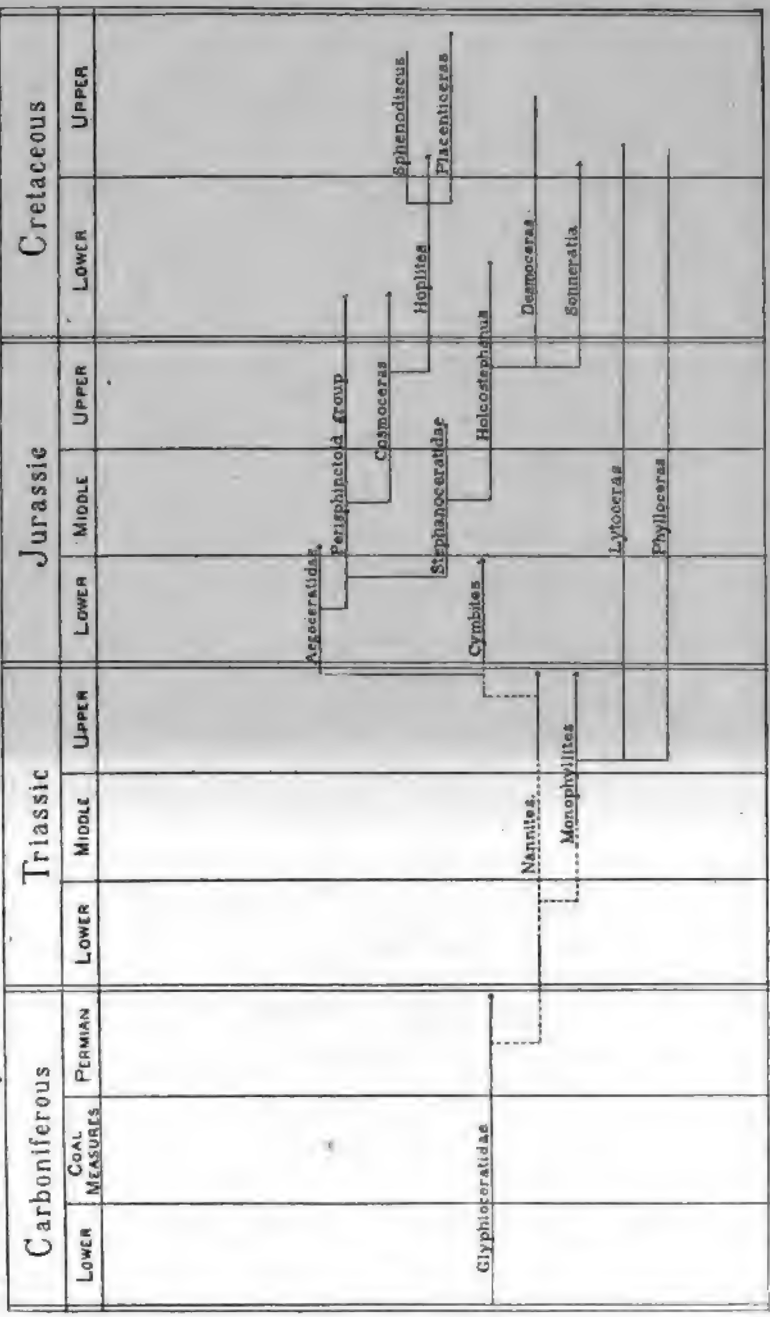
[1] The writer has recently worked out a remarkably perfect series of *Sonneratia stantoni* Anderson MS., *Desmoceras haydeni* Gabb, *D. breweri* Gabb, and *D. hoffmanni* Gabb, on which series the above statements are based.

As to the goniatite radicle of *Hoplites* and of the other perisphinctoids, the writer's investigations point to some glyphioceran form, possibly *Glyphioceras* itself. Now E. Haug (1898, pp. 39, 46, 73) claims that Hyatt's family, Glyphioceratidæ, is nothing but a group of morphological equivalents from three distinct stocks or *phyla*, the Glyphioceratidæ proper, the Gephyroceratidæ, and the Agoniatitidæ; a number of species grouped in this latter phylum are classed together under the new name *Pronannites*, as supposed ancestors of *Nannites*. Just this very group of glyphioceran forms most nearly resembles the goniatite stage of *Hoplites*. Haug is, then, in essential agreement with the writer, although he calls these by other names. Now since this classification of the goniatites, although certainly the best proposed up to this time, is too arbitrary, based too little on what we know, and too much on what may be so, the writer prefers for the present to call the goniatite stage of *Hoplites* glyphioceran, freely admitting that it may eventually be referred to *Pronannites*, or to some other genus at present insufficiently known. And should any of these stages be correlated with *Nomismoceras*, this genus should still, according to E. Holzapfel (1899), be referred not to the Gephyroceratidæ, but to the Glyphioceratidæ, the morphogeny of which group has already been described by the writer (Smith 1897). *Nomismoceras* is probably a derivative of *Glyphioceras*, for some species of *Lytoceras*, after passing through a glyphioceran stage, show what might be called a nomismoceran stage.

Phylogenic Table of Placenticeras and Associated Genera.



Placenticeras californicum *Anderson* (MS.).

PLATE XXV, FIGS. 1–8; PLATE XXVIII, FIG. 6.

Placenticeras californicum is most nearly related to *P. guadaloupæ* (Stoliczka, not Roemer), as described and figured by F. Stoliczka (1861), although it is more compressed laterally, and somewhat rougher shelled than the Indian species. The largest specimen found had the following dimensions:

	mm.
Diameter	120.00
Height of last coil	58.00
Height of last coil from the preceding	45.00
Width of last coil	30.50
Involution	13.00
Width of umbilicus	23.00

This specimen had about six revolutions, showed the body chamber to be about two-thirds of the last whorl, and since there was no further progressive development, seems to have been fully mature. The abdomen is narrow, flattened, with low central keel, and with marginal keels made up of a row of elongated knots. The sides are ornamented with rough sigmoidal ribs, branching out from coarse umbilical knots, and forming the knots on the abdominal shoulder keels.

Another specimen of five and a half revolutions was exactly like the larger one, and gave the following dimensions:—

	mm.
Diameter	77.00
Height of last coil	37.50
Height of last coil from the preceding	27.00
Width of last coil	20.00
Involution	10.50
Width of umbilicus	13.00

Horizon and Locality.—A single specimen of this species was found by Dr. L. G. Yates on the ranch of Mrs. Isabella Jordan, on the Arroyo del Vallé, Alameda county, California, about eight miles southeast of Livermore. Associated with it were found the following species: *Baculites chicoënsis* Trask; *Desmoceras hoffmanni* Gabb; *D. ? selwynianum* Whiteaves; *Hoplites remondi* Gabb; *Holcostephanus ? suciaënsis* Meek; *Lytoceras alamedense* Smith; *Lytoceras batesi* Trask; *L. (Tetragonites)* cf. *cola* Stoliczka; *L.* cf. *timotheanum* Mayor; *Placenticeras pacificum*, sp. nov., Smith; *Phylloceras onoënse* Stanton; *P. ramosum* Meek; *Cinulia obliqua* Gabb; *Inoceramus* cf. *vancouverensis* Shumard;

Trigonia evansana Meek; *Pectunculus veatchi* Gabb, and other species not identified, or not characteristic. This fauna is rather contradictory and puzzling, so that in a former paper (Smith, 1898, p. 138) the writer expressed the opinion that either the fossils from that locality, but from different beds, had not been differentiated in collecting, or that the strata were transitional from Horsetown to Chico. A visit in person to the locality, in the spring of 1899, enabled the writer to find out definitely that there was only one fossiliferous bed; and the identification of two species of *Placenticeras*, the young stages of which were formerly supposed by the writer to be *Hoplites*, place the Chico age, Cenomanian, of these beds almost beyond doubt. A still more certain determination of the age of this species is given by its occurrence, along with *P. pacificum* and a large number of typical Chico species, in the Chico beds one-half mile west of Henley, near Hornbrook, Siskiyou county, California, where it was discovered by Mr. Frank M. Anderson, to whose liberality the writer owes the use of all specimens of *P. californicum* from that locality figured in this paper.[1]

During the summer of 1899 Dr. Stephen Bowers, of Los Angeles, collected a number of Chico fossils in the San Fernando mountains, Los Angeles county; these were sent to the writer for inspection, and several specimens of *P. californicum* were found among them. From its wide range in northern, central, and southern California, always in the same horizon, it is fair to assume that *P. californicum* is characteristic of the lower Chico, or Cenomanian portion of the formation.

Poorly preserved young specimens of this species have a certain resemblance to *Schlœnbachia chicoënsis*, and have been occasionally mistaken for it; but the young stages of the two genera are so entirely different that a mistake is hardly possible if one examines the inner coils.

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[1] In the Proceedings of the California Academy of Sciences, 3d Series, Mr. Anderson will describe this fauna in his monograph on the Cretaceous, and with his permission the writer uses his manuscript name "*Placenticeras californicum* Anderson."

LARVAL AND ADOLESCENT STAGES.

The earliest stages of *Placenticeras californicum* could not be observed on the specimens at hand. The smallest specimen obtained, figured on Pl. XXV, figs. 1 and 2, was in the perisphinctoid stage, and very like the corresponding stage of *Placenticeras pacificum*, except that the shell is a little rougher, and somewhat more evolute than on that species; it consisted of two and three-eighths coils, and had the following dimensions:—

	mm.
Diameter	3.32
Height of last coil	1.44
Height of last coil from the preceding	1.11
Width of last coil	1.33
Involution	0.33
Width of umbilicus	1.16

At about two and a quarter coils the constrictions cease, the ribs end in knots on the abdominal shoulders, and the cosmoceran stage begins at diameter of about four millimetres, just as in *P. pacificum*, but the sculpture is rougher, and the shell more robust. At about three coils and diameter of eight millimetres the sculpture and shape of the shell resemble strongly *Hoplites tuberculatus* Sowerby, of the Gault; this specimen, figured on Pl. XXV, fig. 3, gave the following dimensions:—

	mm.
Diameter	8.00
Height of last coil	4.10
Height of last coil from the preceding	2.80
Width of last coil	3.30
Involution	1.30
Width of umbilicus	1.80

At three and five-eighths coils, diameter 14 mm., the resemblance to the group of *Hoplites interruptus* has become so striking that the young shell might well be taken for an adult of that group, were it not for the fact that this entire group of *Hoplites* was either extinct at this time, or at least had changed entirely into other genera. This specimen is figured on Pl. XXV, figs. 4 and 5, to illustrate the most typical *Hoplites* stage of growth of the species, and to show the striking difference between *P. californicum* and *P. pacificum* at this stage. Both correspond to *Hoplites*, and

both to the group of *H. interruptus*, but the late adolescent stage of *P. pacificum* corresponds closely to *H. splendens*, while *P. californicum* corresponds to the rougher and more evolute species, and retains many cosmoceran characters lacking in the other form.

As the adolescent period advances the resemblance to *Hoplites dufrenoyi* d'Orbigny, of the Gault of Europe, becomes marked, although *P. californicum* differs from the European species in having the ribs finer, more numerous, more sharply bent on the sides, and in having the rows of knots on the abdominal shoulder keels closer together, and weaker. There is also a rather faint second row of knots high up on the sides, where the ribs fork at the sharp forward bend; this is a cosmoceran character lacking on *H. dufrenoyi*. The ribs start out in pairs from a knot on the umbilicus, and between each pair there is usually a single rib intercalated. The rows of knots on the umbilicus, on the sides, and on the abdominal shoulders, are stronger at diameter of fifteen millimetres than at maturity, showing this to have been characteristic of the immediate ancestor of the genus. The relative measurements agree exactly with *H. dufrenoyi*, except that on the Californian species the whorl is broader, and the cross-section polygonal.

The adolescent stage of *P. californicum*, Pl. XXV, figs. 6 and 7, at about four coils, gave the following dimensions:—

	mm.	
Diameter	22.00	1.00
Height of last whorl	10.50	0.48
Height of last whorl from the preceding	8.25	0.37
Width of last whorl	8.00	0.36
Involution	2.75	0.11
Width of umbilicus	6.30	0.28

Compare with these the almost identical measurements of *H. dufrenoyi*, at the same stage of growth:—

	mm.	
Diameter	21.50	1.00
Height of last whorl	10.00	0.47
Height of last whorl from the preceding	7.50	0.35
Width of last whorl	6.50	0.30
Involution	2.75	0.11
Width of umbilicus	6.00	0.28

On the fifth whorl the likeness to *Hoplites* becomes less, and the characters of *Placenticeras* more strongly accentuated; the central abdominal keel stands up almost as high as those on the shoulders, while the sigmoidal ribs are no longer so sharp as in the earlier adolescent stages. This may be considered as the transition to maturity, although the *Hoplites* characters do not disappear at once, nor do the *Placenticeras* characters appear all at the same time; some, in fact, show even at the beginning of the adolescent stage. A specimen illustrating the transition is figured on Pl. XXV, fig. 8; it consists of four and a half coils, and gave the following dimensions:—

	mm.
Diameter	34.50
Height of last coil	18.00
Height of last coil from the preceding	13.00
Width of last coil	9.50
Involution	5.00
Width of umbilicus	5.00

P. californicum might easily be confused with *P. guadaloupæ* Stoliczka (1861) (not Roemer), of the Trichinopoly group, Upper Cretaceous[1], but differs from it in being more compressed laterally, in having rougher sculpture, and in lacking the heavy nodes on the sides below the abdominal shoulders. The two species may be identical, but until we know the limits of variation of them, it would be unsafe to class them together.

Placenticeras pacificum, sp. nov.

PLATE XXIV, FIGS. 1–21; PLATE XXV, FIGS. 9–11; PLATE XXVI; PLATE XXVII, FIGS. 1–13; PLATE XXVIII, FIGS. 1–5.

Placenticeras pacificum is large, discoidal, involute, and laterally compressed, having the typical plate shape of the genus. At maturity the whorl embraces somewhat more than one-half of the preceding; the breadth of the whorl is one-fifth of the diameter, the height of the whorl is three-sevenths, and the width of the umbilicus one-fifth. The body-chamber is about two-thirds of a revolution in length. The abdomen is narrow, flattened, slightly concave, bounded by a row of elongated knots forming rough keels. Up to diameter of about one hundred millimetres, five and a half coils, the shoulder

[1] Stoliczka's species is probably not identical with Roemer's *P. guadaloupæ*, from the Lower Cretaceous of Texas, zone of *Mortoniceras rostratum*.

keels are rather finely notched by the ends of the lateral ribs; at this stage the coarse elongated knots of *Placenticeras* appear, and deep undulations cross the abdomen; a central keel, which has persisted up to this stage, becomes obsolete. The sides are ornamented with rather coarse sigmoidal ribs, bundling on umbilical knots; these show on the cast even more strongly than on the shell. The outer shell has numerous sigmoidal striæ covering the ribs and the interspaces. The umbilicus is moderately narrow, and the shoulders angular, becoming more so as age advances. At five and two-thirds coils the umbilicus is one-sixth of the diameter, while at six and one-third coils it widens out to one-fifth, this change probably indicating old age, for the slackening of the increase of height of the body-chamber shows a decrease in growth force.

The septa consist of an abdominal lobe with a pair of long branches, and seven lateral lobes, all finely digitate, and rather narrow. The saddles are broader and deeply divided by narrow secondary lobes.

Douvillé (1890, p. 288) says that in *Placenticeras* the first, second, and third lateral lobes are probably formed out of divisions of a primary lobe, and that the fourth is really the second primary. But the development of this species shows that the first lateral lobe is developed out of a division of the primary lateral saddle, and that the second, third and fourth lobes are developed out of notches in the primitive first lateral lobe. There are also three auxiliary lobes on the sides, and one on the umbilical shoulders, growing simpler as the umbilicus is approached. This is a common and well known fact, ascribed by Jackson (1899) to the principle of localization of stages of growth, by which more primitive characters are preserved in the dorsal and umbilical portion of the shell. At early maturity these lobes are arranged in a wide backward-pointing curve, but in later growth this curve is not nearly so pronounced. The development of the septa, as shown in the adolescent stages, makes it clear that the three chief lateral lobes are merely modifications out of the three points of the triænidian primitive lateral lobe. This explains the arrangement in a curve, and also the straightening out of this curve as full maturity is approached. This suggests a probable explanation for the large number of lobes found in many ammonites, such as *Placenticeras* and *Sphenodiscus*, although it is not yet known that the development of the latter genus takes place in this way. The arrangement of the lobes in

Placenticeras guadaloupæ Roemer (Pl. XXVIII, fig. 8) suggests this origin for part of them. It is commonly accepted that in the ammonites new elements in the septa develop on the dorsal side near the umbilicus, and appear on the outside only in later growth; here in the development of *Placenticeras* this is decidedly not the case, for the three principal lobes are developed out of one that was on the outside from the very beginning.

Placenticeras pacificum is most nearly akin to *P. californicum*, with which it agrees in the width of the umbilicus, but from which it differs in the more compressed whorl, more numerous, finer ribs, and the smaller size of the knots on the umbilicus. In *P. pacificum* the breadth of the last whorl is one-fifth of the diameter, and in *P. californicum* it is one-fourth, but in the young stages the relative measurements of the two species are very much the same, although there is no danger of confusing them above the diameter of four millimetres. *P. pacificum* might also be compared with *P. guadaloupæ* Stoliczka (1861) (not Roemer), but the Indian species is even thicker than *P. californicum*, and has a row of coarse knots on the umbilical shoulders, and another near the abdominal shoulders, which would distinguish it from either Californian shell. Also, the ribs on the Indian species do not show that strong sigmoidal bend seen on the others.

Horizon and Locality.—*Placenticeras pacificum* was first found by Dr. L. G. Yates on the Arroyo del Vallé, ranch of Mrs. Isabella Jordan, Alameda county, California, about eight miles southeast of Livermore. Associated with it were found the following species: *Baculites chicoënsis* Trask; *Desmoceras hoffmanni* Gabb; *D. ? selwynianum* Whiteaves; *Hoplites remondi* Gabb; *Holcostephanus ? suciænsis* Meek; *Lytoceras alamedense* Smith; *Lytoceras batesi* Trask; *L.* cf. *cola* Stoliczka; *L.* cf. *timotheanum* Mayor; *Placenticeras californicum* Anderson (MS.); *Phylloceras onoënse* Stanton; *P. ramosum* Meek; *Cinulia obliqua* Gabb; *Inoceramus* cf. *vancouverensis* Shumard; *Pectunculus veatchi* Gabb; *Trigonia evansana* Meek; *Nucula truncata* Gabb, and other

species not especially characteristic. This fauna almost undoubtedly indicates the lower part of the Chico formation Cenomanian, Upper Cretaceous.

P. pacificum was afterwards found by Mr. F. M. Anderson one-half mile west of Henley, near Hornbrook, Siskiyou county, California, associated with *P. californicum*, *Pachydiscus newberryanus* Meek, *Phylloceras ramosum* Meek, *Hoplites* cf. *remondi* Gabb, *Chione varians* Gabb, *Mactra ashburneri* Gabb, *Cinulia obliqua* Gabb, *Cylichna costata* Gabb, and a number of other characteristic Chico species; from this locality came the type of the species, figured on Pl. XXVI. Mr. F. Rolfe has recently found this species in the lower Chico beds of the canyon of Silverado creek, near the old coal mine, about two miles east of the mouth of the canyon, where Silverado empties into Santiago creek.

Placenticeras pacificum, since it occurs in the same horizon in northern, middle and southern California, may be taken as characteristic of the lower Chico; so the reference of the beds to the Horsetown, made by the writer (Smith, 1898) in a former paper, will have to be revised, for a careful study has shown the accompanying faunas at all three localities to be characteristic of the Chico, and not of the Horsetown.

Larval Stages.[1]

Phylembryonic Stage.—The young *Placenticeras* was undoubtedly shelled before it was hatched, although it was not possible, on the specimens under investigation, to find out certainly the limits of the primitive embryonic body-chamber; but this seems to have coincided approximately with the limits of the protoconch, although it may have included somewhat more of the spiral coil. Branco (1879, p. 24), on the other hand, is of the opinion that the embryonic shell could not have taken up the entire protoconch, but must have been homologous with the primitive cap-shaped shell of the

[1] In the nomenclature of stages of growth the writer has followed Hyatt's "Phylogeny of an Acquired Characteristic."

gastropods, and only in later growth was the spiral formed. It has, however, been shown by Dr. Amos Brown (1892) that in *Baculites* the limits of the embryo chamber lie between the first and second septa. This has also been observed by the writer on the young of *Baculites chicoënsis*, and on *Lytoceras alamedense*.

The protoconch of *Placenticeras pacificum* (Pl. XXIV, figs. 1–3) has diameter 0.54 mm., and width 0.75 mm.; it is smooth, oval, and covered by the primitive nacreous shell, which extends to the end of the first coil. This protoconch is very similar in all the later ammonites, and is probably an adaptive form, due to life in the egg, and does not represent any ancient ancestral genus, for none of the early cephalopods were shaped like this. It is, then, the typical embryo of the ammonoids, and yet can hardly be said to be correlative with any group of cephalopods.

Ananepionic.—With the formation of the first septum the young ammonite has taken its place among the chambered cephalopods, and has become, for the time being, a nautiloid, although it is not possible, from the exceedingly simple nature of the shell, to correlate it with any especial genus. Nor, indeed, is it strictly homologous with any ancient nautilian form, for the larval ammonite even in its first stages possesses several elements unknown in that group. The first septum, which separates the larval body-chamber from the embryonic shell, is nautilian in character, but the siphuncle begins inside the protoconch with a siphonal knob, or cæcum, and the protoconch itself is calcareous. These are two characters that the nautiloids, even to this day, have never yet acquired. It would, then, be impossible to correlate the ananepionic stage with any ancestral genus, since we have in this stage ammonoid characters pushed back by unequal acceleration, until they occur contemporaneously with more remote ancestral characters. This stage and these characters can not correctly be called adaptive, for they are undoubtedly hereditary, although not inherited at equal rates.

The ananepionic septum (Pl. XXVII, fig. 1) consists of a narrow, undivided, abdominal saddle, and a short lateral saddle; the internal portion of the septum is gently curved, and gives little indication of the lobes and saddles that appear on the second chamber-wall. The only part of the shell that can with certainty be assigned to the ananepionic period of growth is that lying between the first and second septa, but that is probably not all of this second living chamber. The outer nacreous shell is smooth and devoid of all ornament until the end of the first coil, hence it seems likely that the ananepionic body-chamber extended throughout this coil, the end of which is marked by a distinct constriction, and beginning of sculpture, as seen on Pl. XXIV, figs. 3–9. While this portion of the shell became chambered in later larval stages, it was a spiral unchambered coil during the first free stage of the animal. This is true not only of this species of *Placenticeras*, but also of the early larval stages of every ammonite yet seen by the writer, embracing typical genera from the Carboniferous, Trias, Jura, and Cretaceous, retrogressive and progressive forms alike.

Metanepionic.—Following the usage of Hyatt, the middle larval stage is considered to have begun when the shell has assumed ammonoid characters; this happens with the formation of the second septum, and continues as long as only simple goniatite characters are seen. In the older ammonoids the second septum always has an undivided ventral lobe distinctive of the Nautilinidæ and their immediate descendants; but in the later and more specialized ammonites the second septum already has the ventral lobe divided by a siphonal saddle, so that the record of the Nautilinidæ is lost from the shell. The metanepionic stage is shown on Pl. XXIV, figs. 3–7, and its septa on Pl. XXVII, fig. 2. The divided ventral lobe, the lateral lobe and that on the umbilical shoulder, along with the broad low whorl and smooth shell, all remind one strongly of *Glyphioceras*, a genus diagnostic of the Carboniferous; because of this resemblance, and because some member of the Glyphioceratidæ may probably have

been the ancestor of *Hoplites*, this stage is called glyphioceran, although *Pronannites*, or several other genera excluded from this family by some writers, may have been the parent group. In all probability this stage is prosiphonate, although the siphonal collars could not be seen on any specimen, for the higher members of the Glyphioceratidæ become prosiphonate with advancing age, and many of the Cretaceous ammonites investigated become prosiphonate almost as soon as they reach the goniatite stage of development.

At about one-quarter of the first revolution from the protoconch, and at the fourth chamber-wall, a second internal lateral lobe is added, something that no member of the Glyphioceratidæ is known to have possessed;[1] this stage is distinctly goniatitic, and yet not comparable to any known genus, but is probably the result of unequal acceleration of the septation, introducing elements that belonged to later genera. This is shown on Pl. XXVII, fig. 2, and illustrates the multiplication of the lobes by the division of those inside the umbilicus, and gradual pushing of these towards the ventral portion of the shell.

Paranepionic.—At about five-eighths of a coil the new internal lobe reaches the umbilical border, and the shell then has two principal lateral lobes and one auxiliary. The larva has then reached a stage correlative with the goniatites of the Upper Carboniferous. This period of growth did not last long, for shortly after the appearance of the constriction which marks the end of the first coil the septa lose their goniatitic character and become transitional to the ammonite stage. This is shown on Pl. XXVII, figs. 3 and 4, and the outside form of the shell on Pl. XXIV, figs. 6 and 7. At one and one-twelfth coils the shell is transitional from the glyphioceran stage *(Pronannites)* to what resembles closely the genus *Nannites* of the Trias, as

[1] Haug, "Études sur les Goniatites", p. 27, fig. 6, *e*, shows *Pericyclus* with two internal lateral lobes, but this was wrongly copied from Holzapfel's original drawing, "Carbon-Kalke von Erdbach", Pl. III, fig. 6, where only one internal lateral lobe is shown.

shown on Pl. XXIV, figs. 8 and 9; the dimensions at this stage were as follows:—

	mm.
Diameter	1.32
Height of last whorl	0.57
Height of last whorl from the preceding	0.41
Width of last whorl	0.90
Involution	0.16
Width of umbilicus	0.58

If it had not been said that this was a minute young shell taken out of an older individual, any paleontologist would refer it without hesitation to the Glyphioceratidæ, and probably to that group designated by Haug (1898, p. 40) as *Pronannites*, of the Lower Carboniferous; the only character in which it differs from that group is in the two internal lateral lobes, and this, in the opinion of the writer, is the result of unequal acceleration, causing the introduction into the glyphioceran stage of elements that belonged to the descendants of this group. Moreover, there must have been some adult form with this character, for *Paralegoceras* has three external lateral lobes, and must have developed out of a form with glyphioceran or gastrioceran shape and the supernumerary internal lobes, since the new elements usually develop inside the umbilicus. This stage ends at one and one-fourth coils, diameter 1.50 mm., having lasted about one-half a revolution.

ADOLESCENT STAGES.

Ananeanic—Cymbites Stage.—When the young animal has taken on characters that, if occurring in an adult, would stamp it as an ammonite and not a goniatite, it may be considered as adolescent; by this it is not meant to imply that there is any sharp line of demarcation between these two groups, for there are a number of genera that might, with equal propriety, be classed in either division; it is admitted, too, that this manner of subdividing ontogenic stages is artificial, and that it would be much more satisfactory merely to call a stage by the name of the genus with which it is correlated, if we could only be sure of this correlation. But, on account of unequal acceleration, and obscure

development of characters in young ammonites, it is usually impossible to correlate them with certainty with any particular ancestral genus. And this difficulty increases when we leave the larval stages, and are concerned with later growth.

The ananeanic stage begins at one and a-quarter coils, diameter 1.50 mm., when the pointed lateral lobe develops round prolongations on each side and becomes trifid (triænidian); about the same time the lateral saddle becomes indented, showing the first indication of digitation of the septa. Sculpture appears on the shell here for the first time, at first apparently merely a repetition of the constrictions and varices that began at the end of the first coil, then developing faint but distinct ribs between the constrictions. The septa at this stage are shown on Pl. XXVII, fig. 5, one and three-eighths coils, and of the following dimensions:—

	mm.
Diameter	1.70
Height of last whorl	0.76
Height of last coil from the preceding	0.61
Width of last coil	0.95
Involution	0.15
Width of umbilicus	0.68

This first adolescent stage resembles greatly *Cymbites*, *Diaphorites*, and *Pimelites*, any one or all of which may well have been ancestors of the ægoceran stock, although it is impossible to speak with certainty or even probability, especially since the relations of these genera to each other are, as yet, only conjectural; the writer agrees with Buckman (1898), who regards *Cymbites* as the radicle of the ægoceran stock, but makes no mention of the other genera. This stage will be referred to as the *Cymbites* stage.

On Pl. XXIV, figs. 10 and 11, is figured a specimen of *P. pacificum* in the *Cymbites* stage, one and seven-twelfths coils and of the following dimensions:—

	mm.
Diameter	1.99
Height of last coil	0.78
Height of last coil from the preceding	0.66
Width of last coil	0.96
Involution	0.12
Width of umbilicus	0.75

Hyatt (1889) thought that Neumayr's genus was founded on immature specimens, probably of the genus *Agassizceras*, while Haug does not think that the characters upon which the genus was based are sufficiently constant to warrant the separation. But whether *Cymbites* is a valid genus or not, there must have been such a form in the ancestral line of the Ægoceratidæ, and thus of *Hoplites* and *Placenticeras*. So the name will be used until the genus is given a name that will stand, in case the old designation is thrown out.

Cymbites has been found only in the Lower Jura, but from its character must have occurred also in the Trias, for it is simpler in septa than any other ammonite of the Jura. This stage lasts in *Placenticeras* about three-eighths of a coil and ends at diameter 2.20 mm., one and five-eighths of a coil from the protoconch.

Ægoceran Stage.—With the beginning of this part of the adolescent stage the division of the lateral lobe becomes more pronounced, and a secondary indentation begins on the side away from the abdomen. The whorl grows higher, and the rounded exterior gives place to somewhat flattened sides with abdominal shoulders. The sculpture becomes stronger, and the shell is already decidedly ægoceran in appearance. The specimen figured on Pl. XXIV, figs. 12 and 13, and the septa on Pl. XXVII, figs. 6–8, show three internal lateral lobes, an advance in development that is more forward than that of *Hoplites dufrenoyi* at diameter 5.00 mm. At one and seven-eighths coils the young ammonite gave the following dimensions (Pl. XXIV, figs. 12 and 13):—

	mm.
Diameter	2.64
Height of last whorl	1.19
Height of last whorl from the preceding	0.98
Width of last coil	1.16
Involution	0.21
Width of umbilicus	0.80

Perisphinctoid Stage.—At two revolutions, diameter 3.00 mm., the sides become still more flattened and the abdominal shoulders squarer, giving a perisphinctoid aspect, heightened by the frequent varices and the strong

intermediate ribs on the sides and abdomen. It should be noted that the development of the septa has not kept pace with the other characters, for in small adolescent stages of ammonites, on account of their minute size and the thickness of the shell, it is physically impossible for the septa to have the complexity of the corresponding adult genus. Another reason is that the retardation in development of the septa, which is distinctive of *Placenticeras*, begins to show itself here. This retardation becomes more pronounced as the stages advance, so that it becomes more than mere unequal acceleration of characters, for in the septa the *Hoplites* stage of development is never reached, the differentiation of the first lateral lobe into three secondary lobes being already complete. This differentiation shows itself quite distinctly in the perisphinctoid stage. The other characters are not affected by retardation to nearly so great an extent as the septa, or it may be more correct to state that retardation can not be detected in the other characters.

A specimen of two and a-quarter coils, figured on Pl. XXIV, figs. 14 and 15, gave the following dimensions:—

	mm.
Diameter	3.50
Height of last whorl	1.63
Height of last whorl from the preceding	1.36
Width of last whorl	1.40
Involution	0.27
Width of umbilicus	1.06

In everything but the comparative simplicity of the septa this stage is distinctively perisphinctoid, but cannot be correlated with any particular genus of that group, especially in view of the fact that according to the researches of Buckman, quoted above, *Perisphinctes* itself is a degenerate of the stock of the Stephanoceratidæ. The perisphinctoid stage lasts up to two and a-quarter coils, diameter about 3.50 mm.

Metaneanic—Cosmoceras Stage.—In this stage the ribs no longer cross the abdomen, but end in tubercles on the abdominal shoulders, forming well defined shoulder keels, with a furrow between them. The varices and constrictions cease abruptly with the beginning of the stage, at about two and a-quarter coils. The ribs become faint on

the sides, but are strong on the umbilicus and on the shoulders, giving a strong resemblance to *Cosmoceras*, which increases as the stage advances. The septa at first are comparatively simple, although ammonitic. The first lateral lobe begins to lose its identity as a separate lobe, the three divisions of this becoming independent. The outside indentation of the external saddle also begins to assume the proportions of an independent lobe. At the beginning of the stage there are four external primary lateral lobes, and three internal; but about the middle of the third coil, diameter 4.50 mm., the indentation of the external saddle, and the three divisions of the large primary lateral lobe assume the proportions of independent lobes, their arrangement in a curve showing their secondary nature. This is shown on Pl. XXVII, figs. 10–13, where the septa are seen to be remarkably like those of *Diaphorites* Fucini, (Pl. XXVIII, fig. 7), although the shell has long since passed through the stage resembling *Diaphorites*. This is a rather unusual way for new elements to be added to the septa, they usually coming in at the umbilicus. As a consequence of this mode of addition the complexity does not decrease from the abdomen towards the umbilicus, but decreases both ways from the middle of the sides. It would be hard for one that had seen only the adult to believe that the first four lateral lobes had been developed out of one primary lobe. A somewhat similar development has been observed by the writer in the Pinacoceratidæ.

While the almost smooth sides, the strong abdominal shoulder keels made up by growing together of tubercles at the outer ends of the ribs, the narrow umbilicus, and the high narrow whorl all show affinities with *Cosmoceras*, the septa never reach, during this stage, the complexity of that genus. This may be due either to the greater acceleration of development of the form and ornamentation of the shell, or to the physical impossibility of having a chamber-wall take on so many convolutions at the edge in so small a space. Most probably the former explanation is the correct one. A specimen of this stage is figured on

Pl. XXIV, figs. 16 and 17, two and three-eighths coils, and of the following dimensions:—

	mm.
Diameter	4.10
Height of last whorl	1.83
Height of last whorl from the preceding	1.55
Width of last whorl	1.70
Involution	0.28
Width of umbilicus	1.16

On this specimen the *Nannites* stage was seen on the second coil, the perisphinctoid stage on the third coil up to diameter 3.60 mm., two and a quarter coils, while the cosmoceran stage begins just after the last constriction visible on the shell, and lasts up to the end of the third coil, diameter about 7 mm. In this stage the shell resembles a species included by some paleontologists in the genus *Oppelia*, *Ammonites bipartitus* Zieten, as figured by Quenstedt in "Ammoniten des Schwäbischen Jura", Pl. LXXXV; but Quenstedt included that species under the *Ornati*, and evidently considered it as a *Cosmoceras*.

A larger specimen in the *Cosmoceras* stage is figured on Pl. XXIV, figs. 18, 19, showing the distinct bundling of the ribs on the sides, and the coarse abdominal tubercles; this specimen at two and five-sixths coils showed the following dimensions:—

	mm.
Diameter	6.60
Height of last coil	3.15
Height of last coil from the preceding	2.40
Width of last coil	2.07
Involution	0.75
Width of umbilicus	1.46

On this specimen the body-chamber occupied two-thirds of the last coil, and was incomplete even then; the last half coil was taken up by the cosmoceran stage, and the first half by the ægoceran and the perisphinctoid stages.

Just how long the cosmoceran stage lasts or when it ends it is impossible to say, because the change into the next stage is so gradual, and because it comes at such different sizes on different individuals. Since the characters of any one generic stage do not appear or disappear all at once, on account of unequal acceleration of development of these

characters, no one stage is exactly correlative with any particular genus. Thus in naming the stages after genera, it is merely meant that the characters of those genera are predominant. This effect of unequal acceleration becomes more marked as the adolescent stage advances. Near the end of this stage appears the central abdominal keel of *Placenticeras*.

Paraneanic—Hoplites Stage.—Near the beginning of the fourth coil, diameter slightly over 8 mm., the ribs are reduced to mere faint undulations and fine sickle-shaped striæ on the sides and umbilicus, while the external tubercles become almost obsolete, forming mere notches on the continuous abdominal keels. Specific characters begin to appear here, and there is no longer any doubt as to the family to which it belongs; this may be considered as the beginning of the *Hoplites* stage. The septa have not yet reached the complete development of the genus, although on Pl. XXVIII, figs. 1 and 2, a considerable advance over the *Cosmoceras* stage may be seen, especially in the digitation of the secondary lobes. A perfect specimen of three and a half coils, figured on Pl. XXIV, figs. 20 and 21, showed the transition from the cosmoceran to the *Hoplites* stage, and gave the following dimensions:—

	mm.
Diameter	12.00
Height of last whorl	7.00
Height of last whorl from the preceding	5.50
Width of last whorl	3.60
Involution	1.50
Width of umbilicus	2.00

With this stage begin the umbilical knots, which persist and grow stronger, being characteristic of the mature *Placenticeras;* the sculpture becomes fainter, and the tubercles on the shoulder keels subside into faint notches; at the same time the lateral compression becomes more pronounced, and the shell becomes discoidal and very high-whorled. *Placenticeras pacificum* at this stage is wholly unlike *P. californicum*, with which it is associated, being much more compressed and discoidal, with narrower abdomen, flatter sides, much less distinct sculpture, and narrower umbilicus,

although in the earlier adolescent periods both species are very much alike. This stage of growth is most nearly related to *Hoplites splendens* of the Gault, Lower Cretaceous, of Europe, but differs from it in being more compressed laterally, in the narrower abdomen, and the smoother abdominal keels, which on *H. splendens* have a row of tubercles like the adolescent stage of *Placenticeras pacificum*. The septa of the European species differ considerably from those of the Californian, showing none of the degeneration in the approach to *Placenticeras*, which genus, according to Douvillé (1890, p. 290), is a descendant of *Hoplites*.

In the adolescent stage the four secondary lobes, formed from the first lateral by subdivision, swing more and more out of the original curve, and finally in maturity all semblance of the original lobe is lost. The septa then begin to bear some resemblance to *Placenticeras*, as does also the shape of the whorl, and the lack of marked sculpture of the shell. This species is now evidently on the road to becoming a *Placenticeras*, although it has not yet reached that stage of development; this seems to confirm the conjecture of Douvillé as to the origin of that genus, which was formerly classed with the Amaltheidæ.

EPHEBIC OR ADULT STAGE.

When the septa have reached the characters of *Placenticeras*, and undergo no further generic development, the adult stage may be said to have begun. But these characters begin singly, so there is no sudden transition from *Hoplites* to *Placenticeras*. Retardation in development of the septa shows itself early in the adolescent period, and grows more marked as the stage advances, so that the full generic development of *Hoplites* is never reached. At the diameter of 15 mm. the septa have already attained the development of *Placenticeras*, while the shell is decidedly a *Hoplites*. But when the shell becomes extremely discoidal, the umbilical knots strong, the lateral sculpture weak, and the central and marginal ventral keels a decided feature, the shell is no longer comparable to any

species of *Hoplites*, even though many characters of that genus still remain. This may be called the transition to *Placenticeras*.

A specimen with the transition just beginning is figured on Pl. XXV, figs. 9 and 10, four coils, and diameter 20.5 mm., showing the fine sculpture, sharp, slightly notched marginal keels, and narrow umbilicus with faint nodes. A cross-section of this stage is shown on Pl. XXVIII, fig. 5. This stage continues unchanged to four and five-eighths coils, diameter of about 38 mm., where the ribs become suddenly coarse, and undulating nodes begin to show on the marginal keels. A specimen of this stage is figured on Pl. XXV, fig. 11, showing the sudden transition from fine to coarse sculpture. Now, for the first time, this species can certainly be placed among the typical members of *Placenticeras*, as defined by Meek, so the transition period is over, and the animal is really mature in characters, although not yet in size, since it grows nearly five times as large, and adds many more specific characters. This stage continues unchanged for nearly a revolution, the septa growing somewhat more complex, but advancing little beyond those seen at diameter of 15 mm. The septa, at the latest stage where they were visible, five and a-third coils, are shown on Pl. XXVIII, fig. 4. The septa of *P. guadaloupæ* Roemer, copied on Pl. XXVIII, fig. 8, show a decided resemblance to those of *P. pacificum*, but are more finely digitate, and have two more auxiliary lobes; but the arrangement of the three principal lateral lobes in a backward-pointing curve is suggestive of a similar secondary origin. *Placenticeras placenta* Dekay has departed still further from the parent type and has its lobes arranged almost in a straight line, and this character is pushed back by acceleration of development until it is seen even in the larval stages, as shown by Jackson (1899, Pl. XXV, figs. 118 and 119). The early larval stages were not figured, so it is not possible to be sure that the lateral lobes developed by subdivision, but this is very probably the case.

In extreme maturity the central abdominal keel becomes obsolete, and the fine notches on the marginal keels are transformed into rough elongated nodes; the ribs become

coarser, with deeper furrows separating them, crossing even the flattened abdomen. The species now begins to have considerable resemblance to *P. placenta*, although not more than every member of a genus ought to show to the type, but it never departs so far from the *Hoplites* group as does *P. placenta*. The characters of extreme maturity begin at about five and two-thirds coils, diameter 118 mm; how long they lasted, or whether there was any further change it is impossible to say, as the largest specimen seen had diameter 172 mm., and still showed no senile degeneration, unless the widening of the umbilicus is due to deficiency of growth force. This specimen is the type of the species (Pl. XXVI); it is the property of Mr. F. M. Anderson, of Yreka, California.

The genus *Sphenodiscus* was included by Meek as a subgenus under *Placenticeras*, and has been considered by Douvillé as having a common origin with that group in *Hoplites;* both genera seem to have had their origin during the upper part of the Lower Cretaceous, but *Sphenodiscus* does not seem to have been either ancestor or descendant of *Placenticeras*, and, therefore, cannot be considered as a subgenus under it.

Placenticeras shows retardation and degeneration, but *Sphenodiscus* has departed still further from the parent type; its secondary lobes have swung more nearly into a straight line, and have become simpler, by retardation, until they are almost ceratitic in character. But this simplification of the septa can not be referred to reversion to any ancestral characters, since they were never present in any of its ancestors. The ontogeny of this genus is unknown, but it will probably show the larval and earliest adolescent stages normal in number and character of lobes, and with this subdivision in secondary lobes pushed by acceleration of development to an early stage. The life-history of *Spheno discus* would then repeat a part of the ontogeny of *Hoplites*, but can not give the complete record.

TABLE OF CROSS-SECTION OF PLACENTICERAS PACIFICUM.

	Phylembryonic.	*Glyphioceran Metanepionic.*	*Nannites Paranepionic.*	*Cymbites Ananeanic.*	*Agoceras Ananeanic.*	*Coeloceras Metaneanic.*	*Hoplites Stage Paraneanic.*		
	Proto-conch.	½ coil.	1 coil.	1½ cls.	2 coils.	2½ cls.	3 coils.	3½ coils.	4 coils.
	mm.	mm.	mm.	mm.	mm.	mm.	mm.	mm.	mm.
Diameter	0.61	0.88	1.21	1.79	2.65	4.22	7.00	12.00	20.75
Height of last whorl	. . . .	0.48	0.49	0.64	0.98	1.95	3.48	6.20	11.00
Height of last whorl from the preceding . . .	. . . .	0.27	0.33	0.58	0.86	1.57	2.82	5.00	8.70
Width of last whorl	0.80	0.94	0.89	0.91	1.11	1.49	1.99	3.15	5.25
Involution . . .	. . . .	0.21	0.16	0.06	0.12	0.38	0.66	2.20	2.50
Width of umbilicus	. . .	. . . .	0.12	0.58	0.91	1.24	1.58	2.50	4.00

TABLE OF STAGES OF GROWTH OF PLACENTICERAS PACIFICUM.

						Sculpture begins.	Lobes become ammonitic.
	Phylembryonic.	*Ana- to Meta-nepionic.*		*Paranepionic.*			
	Nautilian.	*Glyphioceran.*		*Transition to Nannites.*		*Nannites.*	
	Proto-conch.	P. and ⅓ coil.	P. and ½ coil.	P. and ¾ coil.	1 coil.	1 1/12 coils.	1¼ coils.
	mm.	mm.	mm.	mm.	mm.	mm.	mm.
Diameter	0.54	0.76	0.83	0.98	1.16	1.32	1.57
Height of last coil	. . . . .	0.41	0.34	0.33	0.38	0.57	0.65
Height of last coil from the preceding	. . . . .	0.28	0.25	0.25	0.32	0.41	0.53
Width of last coil	0.75	0.86	0.80	0.80	0.72	0.90	0.90
Involution	. . . . .	0.13	0.09	0.08	0.06	0.16	0.12
Width of umbilicus . . .	. . . .	. . . . .	0.26	0.23	0.46	0.58	0.61

	Distinct ribs begin.	First lateral lobe becomes trifid.			Whorl becomes helmet-shaped.		Sides and abdomen flatten, and the shoulders become distinct.	
	Ananeanic.							
	Cymbites.				*Ægoceran.*		*Perisphinctoid.*	
	1 3/8 coils.	1 1/2 coils.	1 7/12 coils.	1 2/3 coils.	1 3/4 coils.	1 7/8 coils.	2 coils.	2 1/4 coils.
	mm.	mm.	mm.	mm.	mm.	mm.	mm.	mm.
Diameter	1.70	1.82	1.99	2.20	2.40	2.64	2.82	3.50
Height of last coil	0.76	0.79	0.78	0.91	0.94	1.19	1.29	1.63
Height of last coil from the preceding	0.61	0.60	0.66	0.71	0.79	0.98	1.08	1.36
Width of last coil	0.95	0.98	0.96	1.04	1.08	1.16	1.21	1.40
Involution	0.15	0.19	0.12	0.20	0.15	0.21	0.21	0.27
Width of umbilicus . . .	0.68	0.65	0.75	0.81	0.83	0.80	1.00	1.06

	Constrictions cease; abdominal furrow becomes distinct; ribs cease to cross abdomen, and end in knots on the shoulders, they form bundles on the umbilicus, and bifurcate on the sides.				The central abdominal keel begins. The umbilical knots begin.		The sculpture becomes fainter. The two rows of shoulder knots subside into faint notches on almost continuous keels.	
	Metaneanic.					*Paraneanic.*		
	Cosmoceran.					*Hoplites.*		
	2 3/8 coils.	2 1/2 coils.	2 3/4 coils.	2 5/6 coils	3 coils.	3 1/6 coils.	3 5/12 cls.	3 1/2 coils.
Diameter . . .	mm. 4.10	mm. 4.50	mm. 5.90	mm. 6.60	mm. 7.00	mm. 8.50	mm. 10.00	mm. 12.00
Height of last coil	1.83	2.00	2.80	3.15	. . . .	4.60	5.60	7.00
Height of last coil from the preceding . .	1.55	1.66	2.37	2.40	. . . . .	3.70	4.50	5.50
Width of last coil	1.70	1.71	1.85	2.07	. . . . .	2.55	3.00	3.60
Involution . . .	0.28	0.34	0.43	0.75	. . . . .	0.90	1.10	1.50
Width of umbilicus	1.16	1.32	1.40	1.46	. . . . .	1.58	1.70	2.00

	The septa begin to resemble *Placenticeras*.				The fine sickle-shaped ribs become suddenly coarse.		The notched keels give place to strong, elongated nodes, and the central keel disappears.	
	Anephebic.				*Metephebic.*		*Parephebic.*	
	Transition from *Hoplites* to *Placenticeras*.				*Placenticeras.*			
	3¼ coils.	4 coils.	4¼ coils.	4½ coils.	4 5/6 coils	5¼ coils.	5⅔ coils.	6¼ coils.
	mm.	mm.	mm.	mm.	mm.	mm.	mm.	mm.
Diameter . . .	15.00	20.50	26.50	34.50	47.00	67.00	118.00	172.00
Height of last coil	8.00	10.80	14.00	18.00	22.50	36.00	60.00	74.00
Height of last coil from the preceding .	6.50	9.10	11.50	15.00	18.00	. . .	. . . . .	52.00
Width of last coil	4.00	5.00	6.75	7.75	12.00	19.00	25.00	35.00
Involution . . .	1.50	1.70	2.50	3.00	4.50	. . . .	. . . .	22.00
Width of umbilicus	2.50	3.50	4.50	6.00	9.00	11.50	19.00	35.00

CONCLUSION AND SUMMARY OF RESULTS.

The development of *Placenticeras* shows that it is possible, in spite of dogmatic assertions to the contrary, to decipher the race history of an animal in its individual ontogeny. But the interpretation of ontogenic data is no simple problem of mere comparison of growth stages with antecedent genera; we must know the sources of error and apply the necessary corrections. We must guard against unequal acceleration, by which in the ontogeny of descendants characters are caused to occur together that belonged to different geologic generations of ancestors. An example of this is the central abdominal keel, that begins near the end of the cosmoceran stage, when no *Cosmoceras* nor even *Hoplites* ever had this; it is an adult character pushed back further than the other placenticeran characters by unequal acceleration. This inexact parallelism makes it impossible in many cases to correlate exactly a growth stage with the ancestral genus; otherwise it would be better to name the

stage after the correlative genus, instead of using an arbitrary and artificial nomenclature such as has been adopted. When ontogenic stages are named after genera, it merely means that the characters of those genera are predominant.

Retardation plays an important part in the species discussed in this paper, showing itself especially in the septa, causing them to fail to reach the full development of *Hoplites*, the immediate ancestor of *Placenticeras*, and preventing individual ontogeny from giving the full ancestral record.

It is here demonstrated that new elements of the septa, contrary to the accepted belief, are sometimes added by subdivision of primary lobes on the outside, and not necessarily always in the part concealed by the involution, thus giving a reasonable explanation of the large number of small lobes found in such genera as *Beloceras*, *Pinacoceras*, and *Sphenodiscus*. The occurrence of lobes of this character does not show that such genera are related, but merely that each is a gerontic form, and that descendants of these are not to be expected in later formations. This does not apply to *Arcestes*, which has a large number of primary lobes, visible even on the second septum from the protoconch.

The stages wholly lost out of the ontogeny lie between the nautilian protoconch and the glyphioceran larval stage; this unrecorded part of the development is thought to have corresponded to the time spent in the egg. All later stages are recorded in ontogeny with a fair degree of distinctness.

The protoconch can not be correlated with any nautiloid, but the later stages can be compared with ammonoid genera, the exactness of the correlation becoming less as the stage advances, on account of unequal acceleration of development of ancestral characters, but on the other hand easier, on account of the greater number of characters one has to deal with.

The earliest larval stage is nautiloid in septa, but ammonoid in its calcareous protoconch. The middle larval stage is comparable with the Paleozoic group Glyphioceratidæ, probably *Glyphioceras* itself; the last larval stage is analogous to *Nannites*, a genus characteristic of the earliest Mesozoic.

In the adolescent period *Placenticeras* goes through at first a stage corresponding to *Cymbites*, or at least some *Cymbites*-like form, of the Upper Trias; then to some ægoceran genus of Upper Triassic or Lower Jurassic age; then to some one of the earlier perisphinctoid genera; then to *Cosmoceras* of the Jura, and lastly to *Hoplites* of the Cretaceous. It is thus demonstrated by ontogenic study that *Placenticeras* developed out of *Hoplites*, and thus belongs with that group near the Stephanoceratidæ, and not under the Amaltheidæ, with which it is classed in nearly all text-books. This relationship is shown also by the number of ammonite species intermediate in character between *Hoplites* and *Placenticeras*, although they are conventionally grouped under one or the other genus.

It is a mistake to class *Sphenodiscus* as a subgenus under *Placenticeras*, for it is neither ancestor nor descendant of that genus, but a parallel, independent development from the common stock *Hoplites*. The same retardation that caused the peculiar arrangement of the lobes in *Placenticeras* has gone even further towards simplifying the septa of *Sphenodiscus*, although this can not correctly, in either case, be ascribed to reversion, since while both fail to reach, in some respects, the full development of their ancestors, they do not return to the characters of any of their predecessors.

A parallel study of the ontogeny of two closely related species shows that the results must be interpreted with caution. *Placenticeras pacificum* and *P. californicum* certainly came from the same group of *Hoplites*, and probably from the same species, but in the late adolescent stage they are unlike, just as easily distinguishable as at maturity, owing to pushing back of specific characters into the adolescent period. Even in the *Cosmoceras* stage the two are quite distinct; the difference becomes less in the perisphinctoid stage, and undoubtedly the larval stages would be precisely alike in both. But this does not mean that the line of descent was the same only through the larval stages, and that the two species branched out from different perisphinctoid forms, for in all probability the perisphinctoid, cosmoceran,

and *Hoplites* ancestors were the same for both species, and the differentiation could not have taken place before the Lower Cretaceous; the difference is due to unequal acceleration of characters.

The development of *Placenticeras* gives us an unusually fine illustration of the law of acceleration, or *tachygenesis*, with its two corollaries, unequal acceleration and retardation. In species from the Paleozoic or early Mesozoic we get better correlations of growth stages with ancestral genera, for with them there is little unequal acceleration, and almost no retardation apparent. But they are usually so poorly preserved that this sort of work is impossible with them. In Cretaceous species the preservation is usually better and the young specimens may be taken out from the old in good state of preservation, and the comparison with supposed ancestral genera facilitated. But in these later genera, so far removed in time from their origin, the development is so much more complex, on account of unequal acceleration, and in some cases on account of retardation, that correlation with ancestral genera is no longer a simple problem, although all the more fascinating because of its difficulty; it calls to its aid all the resources of biology and geology.

STANFORD UNIVERSITY,
CALIFORNIA,
March, 1900.

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EXPLANATION OF PLATE XXIV.

Placenticeras pacificum, sp. nov.

Figs. 1, 2. Protoconch from front and from above; 20 times enlarged. Arroyo del Vallé, Alameda County, California.

Fig. 3. Larval coil, diameter 1.16 mm., showing phylembryonic protoconch in the centre; 20 times enlarged. Arroyo del Vallé, Alameda County, California.

Figs. 4, 5. Transition from phylembryonic to ana- to meta-nepionic stages, diameter 0.76 mm., protoconch and one-third coil; 20 times enlarged. Arroyo del Vallé, Alameda County, California.

Figs. 6, 7. Protoconch and three-quarters of a coil, diameter 0.98 mm., beginning of the paranepionic stage; 20 times enlarged. Arroyo del Vallé, Alameda County, California.

Figs. 8, 9. Paranepionic, transition from glyphioceran to *Nannites*, one and one-twelfth coils; 20 times enlarged. Arroyo del Vallé, Alameda County, California.

Figs. 10, 11. Early adolescent (ananeanic), *Cymbites* stage, diameter 1.99 mm., one and seven-twelfths coils; 13 times enlarged. Henley, Siskiyou County, California.

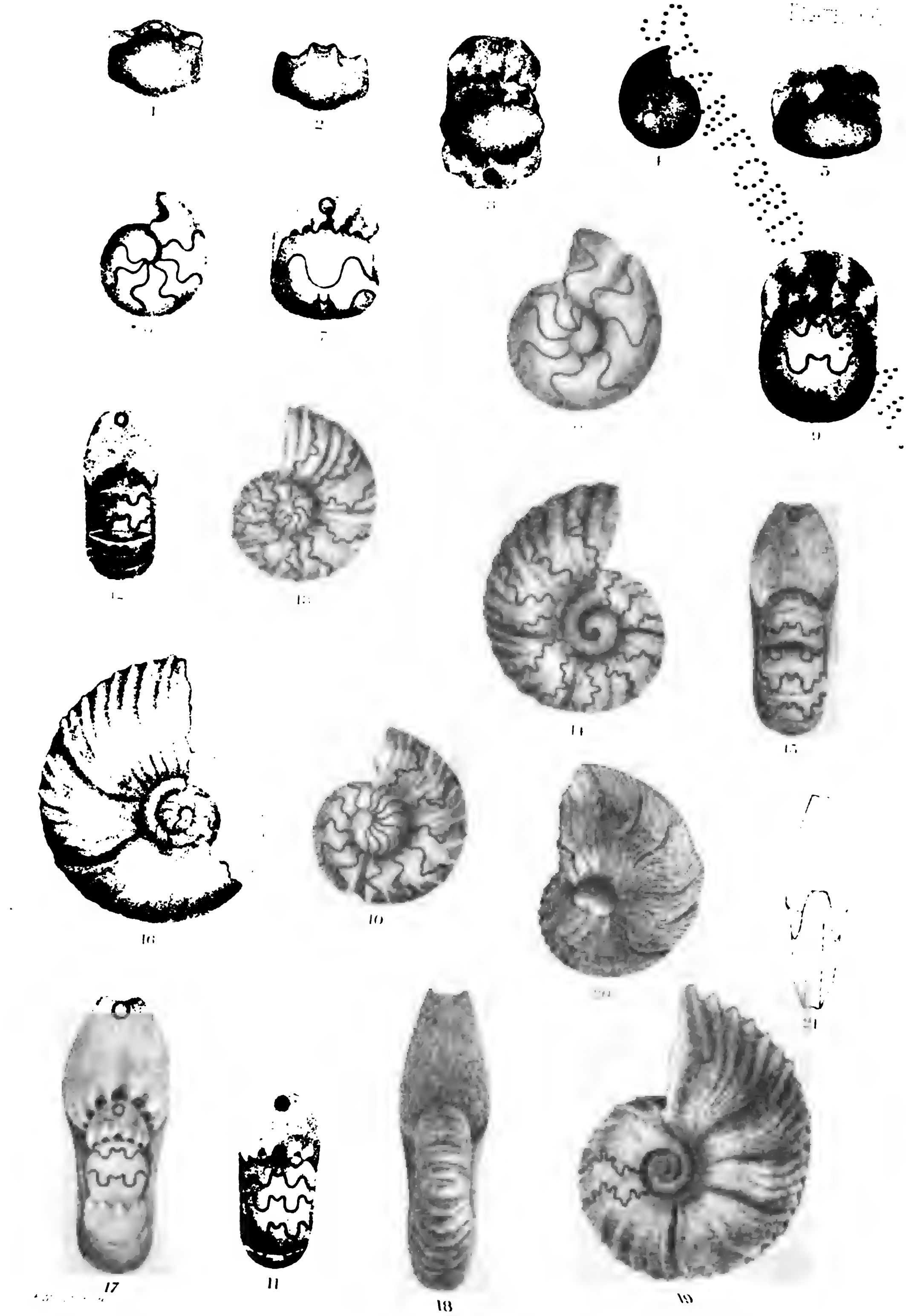
Figs. 12, 13. Ananeanic, ægoceran stage, one and seven-eighths coils, diameter 2.64 mm.; 10 times enlarged. Arroyo del Vallé, Alameda County, California.

Figs. 14, 15. Ananeanic, perisphinctoid stage, diameter 3.50 mm., two and a quarter coils; 10 times enlarged. Arroyo del Vallé, Alameda County, California.

Figs. 16, 17. Metaneanic, transition from perisphinctoid to the cosmoceran stage, diameter 4.10 mm., two and three-eighths coils; 10 times enlarged. Arroyo del Vallé, Alameda County, California.

Figs. 18, 19. Metaneanic, cosmoceran stage, diameter 6.60 mm., two and three-quarters coils; 7 times enlarged. Arroyo del Vallé, Alameda County, California.

Figs. 20, 21. Beginning of paraneanic stage, transition from cosmoceran to the *Hoplites* stage, diameter 12 mm., three and a half coils; 2.7 times enlarged. Henley, Siskiyou County, California.



PLACENTICERAS PACIFICUM.

EXPLANATION OF PLATE XXV.

Figs. 1, 2. *Placenticeras californicum*, adolescent, perisphinctoid stage, two and five-sixteenths coils, diameter 3.32 mm.; 10 times enlarged. Henley, California.

Fig. 3. *P. californicum*, adolescent, transition from cosmoceran to the *Hoplites* stage; three coils, diameter 8 mm.; 2.7 times enlarged. Henley, California.

Figs. 4, 5. *P. californicum*, adolescent, typical *Hoplites* stage, three and five-eighths coils, diameter 14 mm.; twice enlarged. Henley, California.

Figs. 6, 7. *P. californicum*, adolescent, *Hoplites* stage, four coils, diameter 22 mm.; twice enlarged. Arroyo del Vallé, Alameda County, California.

Fig. 8. *P. californicum*, transition from *Hoplites* to *Placenticeras*, four and a half coils, diameter 34.50 mm.; twice enlarged. Henley, California.

Figs. 9, 10. *P. pacificum*, end of *Hoplites* stage, four coils, diameter 20.5 mm.; 2.7 times enlarged. Arroyo del Vallé, California.

Fig. 11. *P. pacificum*, transition to *Placenticeras*, diameter 47 mm., four and five-sixths coils; natural size. Henley, California.

[illegible] PLACENTICERAS CALIFORNICUM. FIGS. [illegible] PLACENTICERAS [illegible]

EXPLANATION OF PLATE XXVI.

(From a photograph by Franklin, Palo Alto, California.)

Placenticeras pacificum, sp. nov.

Adult shell, diameter 172 mm., six and a sixth coils, natural size. Henley, California. Type specimen, property of Frank M. Anderson, Yreka, California.

PLACENTICERAS PACIFICUM, SP. NOV.

EXPLANATION OF PLATE XXVII.

Development of the Septa of *Placenticeras pacificum.*

Fig. 1. First septum, ananepionic, nautiloid stage; 20/1.

Fig. 2. Septum at one-half coil, diameter 0.83 mm., metanepionic, glyphioceran stage; 20/1.

Fig. 3. Septum at one coil, diameter 1.16 mm., glyphioceran stage; 20/1.

Fig. 4. Septum at one and one-twelfth coils, diameter 1.32 mm., end of the paranepionic or end of larval stage, *Nannites* stage; 20/1.

Fig. 5. Septum at one and three-eighths coils, diameter 1.70 mm.; 20/1.

Fig. 6. Septum at one and five-eighths coils, diameter 2.20 mm., 20/1.

Fig. 7. Septum at one and three-quarters coils, diameter 2.40 mm., 20/1.

Fig. 8. Septum at one and seven-eighths coils, diameter 2.70 mm., transitional from Ægoceratidæ to the Perisphinctinæ; 20/1.

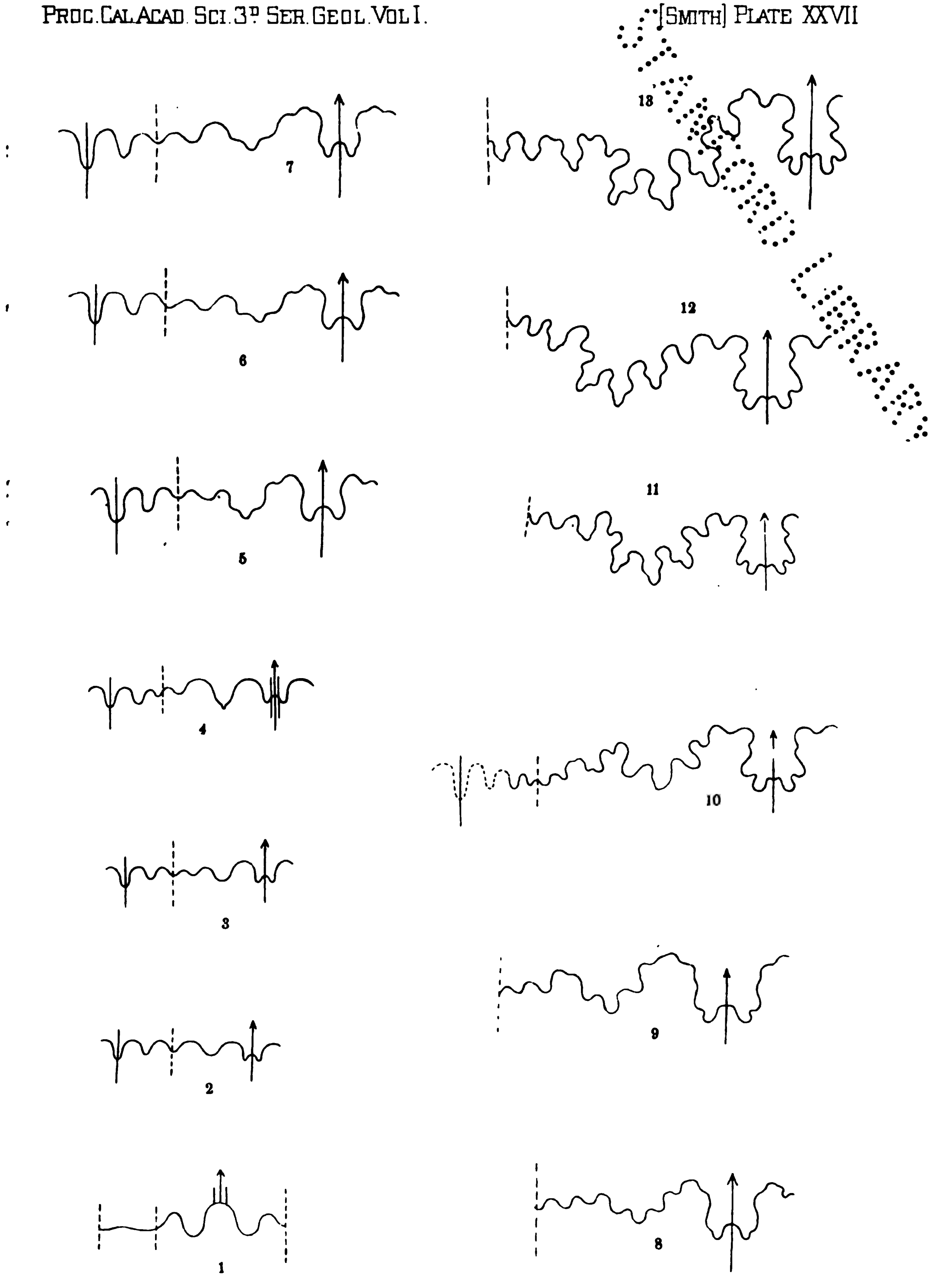
Fig. 9. Septum at two coils, diameter 3 mm.; 20/1.

Fig. 10. Septum at two and three-eighths coils, diameter 4.10 mm., *Cosmoceras* stage; 13/1.

Fig. 11. Septum at two and a half coils, diameter 4.50 mm., paraneanic, *Cosmoceras* stage; 14/1.

Fig. 12. Septum at two and seven-twelfths coils, diameter 5.50 mm., *Cosmoceras* stage; 14/1.

Fig. 13. Septum at two and three-quarters coils, diameter 6.25 mm., paraneanic, *Cosmoceras* stage; 14/1.



F. H. SMITH DEL.

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PLACENTICERAS PACIFICUM.

EXPLANATION OF PLATE XXVIII.

Development of the Septa of *Placenticeras pacificum.*

Fig. 1. *Placenticeras pacificum*, septum at three and a sixth coils, diameter 8.50 mm., adolescent, about end of cosmoceran stage; 14/1.

Fig. 2. *P. pacificum*, septum at three and a half coils, diameter 12 mm., *Hoplites* stage; 14/1.

Fig. 3. *P. pacificum*, septum at three and three-quarters coils, diameter 14.50 mm.; the septa already show placenticeran characters, although the shell is still in the *Hoplites* stage; 9 times enlarged.

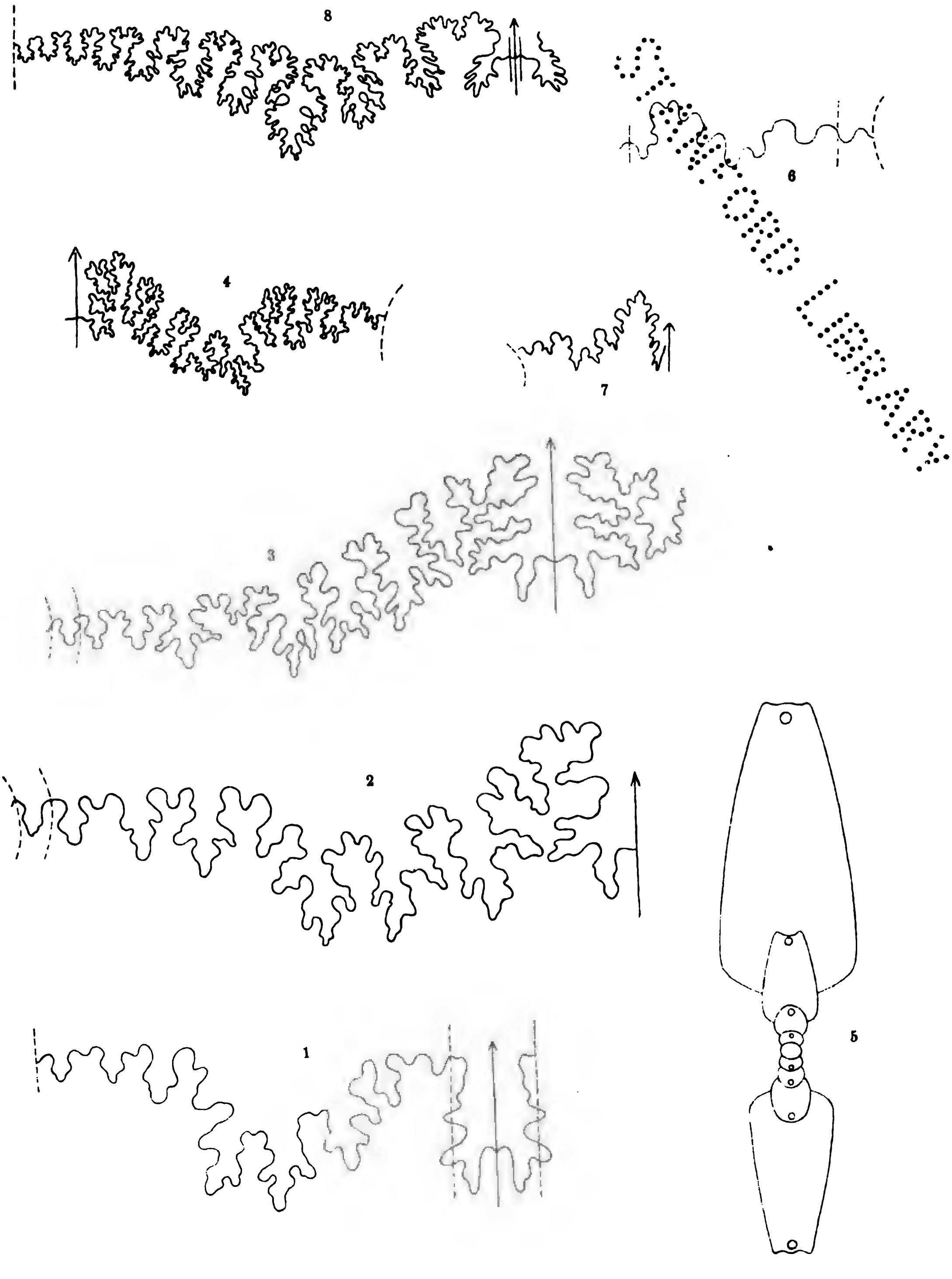
Fig. 4. *P. pacificum*, septum at maturity; natural size.

Fig. 5. *P. pacificum*, cross-section at four coils, adolescent, diameter 20.75 mm., showing inner whorls helmet-shaped, and the transition to the compressed, flat-sided placenticeran whorl; 4 times enlarged.

Fig. 6. Septum of *P. californicum*, adolescent, cosmoceran stage, two and three-quarters coils, diameter 4.70 mm.; 13 times enlarged.

Fig. 7. Early adult septum of *Diaphorites vetulonius* Fucini, for comparison. (After Fucini, *Pal. Ital.*, 1896, Vol. II, Pl. XXV, fig. 8.)

Fig. 8. Septum of *Placenticeras guadaloupæ* Roemer, for comparison. (After Roemer, Kreidebildungen von Texas, Pl. II, fig. 1.)



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FIGS. 1-5. PLACENTICERAS PACIFICUM.
FIG. 6. PLACENTICERAS CALIFORNICUM.
FIG. 7. DIAPHORITES VETULONIUS.
FIG. 8. PLACENTICERAS GUADALOUPÆ.

PROCEEDINGS

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Foraminifera from the Tertiary of California

BY

FREDERICK CHAPMAN,

Assoc. Linn. Soc. Lond.

WITH TWO PLATES

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FORAMINIFERA FROM THE TERTIARY OF CALIFORNIA.

BY FREDERICK CHAPMAN,

Assoc. Linn. Soc. Lond.

PLATES XXIX, XXX.

INTRODUCTION.

IN consideration of the value of Foraminifera as indices of the relative age of a fossiliferous deposit, not so much with regard to isolated species, but with the general faunal aspect of the group, the present collection affords many points of interest.

Presuming the conditions of life and surroundings to be equal, we may fairly expect to find foraminiferal assemblages in many different areas of the earth's superficial deposits very closely related as to their percentage of species in common, provided they are comparable with one another, either homotaxially (with regard to higher groups of animal remains), or chronologically. On the other hand, we rarely find foraminiferal assemblages from deposits of decidedly different ages with a high percentage of species in common.

In March, 1897, I was favored by Dr. J. C. Merriam of the University of California with a sample of Tertiary marl from California, accompanied by a request that I would investigate the rock for its Foraminifera.

In November of the same year Dr. Merriam supplied me with further specimens of a somewhat similar rock, and which was richer in organisms than that first sent.

All the samples have now been examined and yield the following results.

The sample first received, labeled "Miocene (?) California," is a close-textured grey-brown marl. The fractured surface of the rock when examined with a lens reveals numerous foraminiferal shells, broken across, and with the chambers quite empty. This sample did not afford

 December 21, 1900.

any species which was not present in the richer sample received afterwards.

The second samples bear the label "from a well in Santa Clara Co." The rock is a grey-brown marl, somewhat paler than the first specimen, rather shaley, and crowded with Foraminifera, which appear as minute white specks disseminated through it.

The matrix of the foraminiferal marl when seen in a thin section is of a rich brown color, and appears to be derived from the decomposition of basaltic or palagonitic material.

From the fact that the foraminiferal shells have their chambers, in nearly all cases, quite empty, it seems reasonable to conclude that the enveloping mud was quickly hardened around the organisms; thus leaving the shells without an infilling, which is so usual elsewhere in the case of Foraminifera of these particular genera.

In making a comparison of the various foraminiferal faunas, we find that this of the Californian Tertiary has its nearest analogue in the beds of Monte Bartolomeo on the Lago di Garda, Italy, the Foraminifera of which were so well described and figured by Dr. Egger in 1895,[1] and classed as Older Pliocene. The Foraminifera of the two deposits are strikingly similar, with the chief difference that the Californian marl is not quite so rich in species.

Another noteworthy assemblage, containing a large proportion of the Californian species, is that of the tertiaries of the Vienna Basin, probably of Miocene age.[2]

The Miocene of America, so far as the beds have yet been examined for Foraminifera, does not yield a very large proportion of species in common with this present deposit, but bears a general resemblance to it. The Miocene beds of the States of New Jersey, Alabama, Virginia and Maryland have been examined for Foraminifera by Drs. A. Woodward[3] and R. M. Bagg.[4]

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[1] "Fossile Foraminiferen von Monte Bartolomeo am Gardasee," Jahresbericht XVI, des Naturhistorischen Vereins Passau, 1895.

[2] d'Orbigny, 1846, "Foraminifères fossiles du Bassin tertiare de Vienne." Paris.

[3] "Note on the Foraminiferal Fauna of Miocene Beds at Petersburg, Virginia." *Journ. N. York Microscopical Soc.*, Vol. III, 1887, pp. 16, 17. Also "Foraminifera found in the Borings from Artesian Wells located in New Jersey and Alabama." *Journ. N. York Micr. Soc.*, Jan., 1898, pp. 1–3.

[4] "The Tertiary and Pleistocene Foraminifera of the Middle Atlantic Slope." *Bull. Amer. Palæont.*, Vol. II, No. 10, 1898.

DESCRIPTION OF THE SPECIES.

Family TEXTULARIIDÆ.

Subfamily BULIMININÆ.

Bulimina *d'Orbigny* [1826].

Bulimina elongata *d'Orbigny.*

PLATE XXIX, FIG. 1.

Bulimina elongata D'ORBIGNY, 1846, Foram. Foss. Vien., p. 187, Pl. XI, figs. 19, 20.
Bulimina eocena HANTKEN, 1872, Jahrb. d. k. ung. geol. Anstalt, Bd. I, p. 136, Pl. II, fig. 16.
Bulimina elongata HANTKEN, 1875, ibid., Bd. IV, Pt. 1, pp. 61, 62, Pl. X, figs. 7 *a*, *b*. EGGER, 1895, Naturhist. Ver. Passau, Jahresber. XVI, pp. 15, 16, Pl. III, figs. 12 *a*, *b*. A. WOODWARD, 1898, Journ. N. York Micr. Soc., p. 1. BAGG, 1898, Bull. Amer. Palæont., Vol. II, No. 10, p. 316.

This species is quite typical in the present collection. It also occurs in many of the tertiary deposits of Europe, and it has been recorded by A. Woodward from the Miocene of Atlantic City, New Jersey, and by R. M. Bagg from Plum Point, Maryland, in beds of the same age.

Santa Clara County, California; very common.

Bulimina elegantissima *d'Orbigny.*

PLATE XXIX, FIG. 2.

Bulimina elegantissima D'ORBIGNY, 1839, Foram. Amér. Mérid., p. 51, Pl. VII, figs, 13, 14.
Bulimina pulchra TERQUEM, 1882, Mém. Soc. géol. France, Sér. 3, Tome II, Mém. 3, p. 114, Pl. XII, figs. 8-12.
Bulimina elegantissima BRADY, 1884, Chall. Rept., Vol. IX, pp. 402, 403, Pl. L, figs. 20-22. A. WOODWARD, 1898, Journ. N. York Micr. Soc, p. 3.

Although not quite typical, several of the specimens found are without doubt referable to this species. As a fossil it occurs in several Eocene and Post-tertiary deposits. Dr. A. Woodward has found this species in the Miocene of Mobile, Alabama.

Santa Clara County, California; frequent.

Bulimina elegans *d'Orbigny.*

PLATE XXIX, FIG. 3.

Bulimina elegans D'ORBIGNY, 1826, Ann. Sci. nat., Tome VII, p. 270, No. 10, Modèles No. 9. PARKER, JONES AND BRADY, 1865, Ann. and Mag. Nat. Hist., Ser. 3, Vol. XVI, p. 20, Pl. II, fig. 64. BRADY, 1884, Chall. Rept., Vol. IX, pp. 398, 399, Pl. L, figs. 1-4. EGGER, 1895, Naturhist. Ver. Passau, Jahresber. XVI, p. 16, Pl. III, fig. 9. T. RUPERT JONES, 1895, Foram. Crag, Pt. II, (Pal. Soc. Mon.), pp. 162, 163, woodcut fig. 17. A. WOODWARD, 1898, Journ. N. York Micr. Soc., pp. 1 and 3.

Until lately this species was known only from recent deposits, but has since been obtained from the Upper Chalk (Chapman), from the Older Pliocene (Egger), and from the Pliocene of Suffolk and Antwerp (Rupert Jones). A. Woodward has found this form also in the Miocene of Atlantic City, New Jersey, and Mobile, Alabama.

The specimen of *B. elegans* here figured is somewhat more elongated than is usual, but it is in other respects characteristic.

Santa Clara County, California; very rare.

Bulimina affinis *d'Orbigny.*

PLATE XXIX, FIG. 4.

Bulimina affinis D'ORBIGNY, 1839, Foram. Cuba, p. 109, Pl. II, figs. 25, 26.

Bulimina ovulum REUSS, 1850, Haidinger's Naturw. Abhandl., Bd. IV, p. 38, Pl. IV, fig. 9.

Bulimina affinis BRADY, 1884, Chall. Rept., Vol. IX, pp. 400, 401, Pl. L, figs. 14 *a*, *b*. EGGER, 1895, Naturhist. Ver. Passau, Jahresber. XVI, pp. 14, 15, Pl. IV, figs. 4, 5.

The geological range of this species is more extensive than that of the other *Bulimina* of this series, since it first appears in the Lower Greensand of Surrey, England.

Santa Clara County, California; frequent.

Bulimina buchiana *d'Orbigny.*

PLATE XXIX, FIG. 5.

Bulimina buchiana D'ORBIGNY, 1846, Foram. Foss. Vienne, p. 186, Pl. XI, figs. 15-18.

Bulimina truncana GÜMBEL, 1868, Abhandl. d. k. bayer. Akad. Wiss., II. Cl., Bd. X, p. 644, Pl. II, figs. 77, *a*, *b*.

Bulimina buchiana BRADY, 1884, Chall. Rept., Vol. IX, pp. 407, 408, Pl. LI, figs. 18, 19. EGGER, 1895, Naturhist. Ver. Passau, Jahresber. XVI, p. 18, Pl. IV, figs. 9–11. BAGG, 1898, Bull. Amer. Palæont., Vol. II, No. 10, pp. 315, 316, Pl. II, fig. 4.

Bulimina buchiana has been noticed in many Tertiary beds. It was originally described from the Miocene of the Vienna Basin and it has been found by Dr. Bagg in the Miocene of Norfolk, Virginia. It was also found by Dr. Egger in the Older Pliocene of Monte Bartolomeo.

California (first sample very rare), and from a well in Santa Clara County, California; frequent.

Bolivina *d'Orbigny* [1839].

Bolivina dilatata *Reuss.*

PLATE XXIX, FIG. 6.

Bolivina dilatata REUSS, 1849, Denk. Akad. Wiss. Wien, Bd. I, p. 381, Taf. XLVIII, fig. 15. TERRIGI, 1880, Atti dell' Accad. Pont., Ann. XXXIII, p. 197, Pl. II, fig. 42. BRADY, 1884, Chall. Rept., Vol. IX, p. 418, Pl. LII, figs. 20, 21. EGGER, 1895, Naturhist. Ver. Passau, Jahresber. XVI, pp. 10, 11, Pl. I, figs. 6 *a–c*.

This species first makes its appearance in the Miocene and it occurs in succeeding deposits to the Recent. Egger records it from the Older Pliocene of Monte Bartolomeo.

The specimens from California are very variable as to proportionate length and breadth.

Santa Clara County, California; very common.

Bolivina dilatata *Reuss*, var. **angusta** *Egger.*

PLATE XXIX, FIG. 7.

Bolivina dilatata REUSS, var. *angusta* EGGER, 1895, Naturhist. Ver. Passau, Jahresber. XVI, p. 11, Pl. I, fig. 7; figs. 12 *a*, *b*.

Egger describes this variety from Monte Bartolomeo. It is characterized by the lengthened test and the comparatively sharp-pointed aboral end.

Santa Clara County, California; common.

Bolivina æenariensis *(Costa).*

PLATE XXIX, FIG. 8.

Brizalina æenariensis COSTA, 1856, Atti dell' Accad. Pont., Tome VII, p. 297, Pl. XV, fig. 1, *A*, *B*.

Bolivina æenariensis BRADY, 1882, Proc. Roy. Soc. Edin., Vol. XI, p. 711, — Table. Idem, 1884, Chall. Rept., Vol. IX, p. 423, Pl. LIII, figs. 10, 11. BRADY, PARKER and JONES, 1888, Trans. Zool. Soc. Lond., Vol. XII, Pt. 7, p. 221, Pl. XLIII, figs. 2, 4, 5. MALAGOLI, 1889, Boll. Soc. Geol. Ital., Vol. VII, p. 377, Pl. XIV, figs. 11, 12. JONES, 1895, Monogr. Crag Foram. (Pal. Soc.), Pt. II, pp. 169, 170, Pl. VI, fig. 21.

This is a shallow-water species. Its geological range commences from the Miocene age. It is very common in the material from a well in Santa Clara County, California.

Family LAGENIDÆ.

Subfamily LAGENINÆ.

Lagena *Walker & Jacob* [1784].

Lagena sulcata *(Walker & Jacob).*

PLATE XXIX, FIG. 9.

Serpula (Lagena) sulcata W. & J., 1798, Adams' Essays, Kanmacher's Ed., p. 634, Pl. XIV, fig. 5.

Lagena sulcata BRADY, 1884, Chall. Rept. Vol. IX, pp. 462, 463, Pl. LVII, figs. 23, 26, 33, 34. JONES, 1895, Monogr. Crag Foram. (Pal. Soc.), Pt. II, pp. 186–188, Pl. I, figs. 40, 41.

This species is, geologically speaking, one of the oldest of the genus, its range extending as far back as the Ordovician. As to depth of water, it is not restricted, although generally found in shallow or moderately shallow deposits.

From a well in Santa Clara County, California; frequent.

Lagena crenata *Parker & Jones.*

PLATE XXIX, FIG. 10.

Lagena crenata PARKER AND JONES, 1865, Phil. Trans., Vol. CLV, p. 420, Pl. XVIII, figs. 4 *a*, *b*. BRADY, 1866, Rep. Brit. Assoc., Trans. Sections, p. 70; Idem, 1884, Chall. Rept., Vol. IX, p. 467, Pl. LVII, figs. 15, 21.

This rare species makes its first appearance in Miocene deposits. At the present day it is found usually in shallow or moderately shallow water, but has occasionally been found at depths of over 2,000 fathoms.

From a well in Santa Clara County, California; one specimen.

Subfamily NODOSARIINÆ.

Nodosaria *Lamarck* [1816].

Nodosaria radicula *(Linné).*

PLATE XXIX, FIG. 11.

Nautilus radicula LINNÉ, 1767, Syst. Nat., 12th Ed., pp. 285, 1164; —1788, Ibid., 13th (Gmelin's) Ed., Vol. I, Pt. 6, p. 3373, No. 18. MONTAGU, 1803, Test. Brit., p. 197, Pl. VI, fig. 4.

Nodosaria radicula D'ORBIGNY, 1826, Ann. Sci. nat., Tome VII, p. 252, No. 3, Modèle No. 1. BRADY, 1884, Chall. Rept., Vol. IX, p. 495, Pl. LXI, figs. 28-31. EGGER, 1895, Naturhist. Ver. Passau, Jahresber. XVI, p. 20, Pl. II, fig. 3.

A species having a wide range both as to depth and geographical distribution. Its geological range is also extensive, dating as far back as the Permian.

Santa Clara County, California; occasional.

Nodosaria pauperata *d'Orbigny.*

PLATE XXIX, FIG. 12.

Dentalina pauperata D'ORBIGNY, 1846, For. Foss. Vienne, p. 46, Pl. I, figs. 57, 58.

Nodosaria (Dentalina) pauperata BRADY, 1884, Chall. Rept., Vol. IX, pp. 500, 501; woodcuts, figs. 14 *a-c*. RUPERT JONES, 1896, Monograph Crag Foram., Part III, 1895, pp. 224–226, Pl. I, figs. 13-18, 20.

This species ranges from the Lias to deposits of recent date. It is a variable form in the Californian deposits; some of the specimens closely approach *N. consobrina*, whilst others pass into *N. farcimen* or *N. soluta*.

Santa Clara County, California; frequent.

Nodosaria farcimen *Reuss* (after *Soldani*).

PLATE XXIX, FIG. 13.

"*Orthoceras farcimen*" SOLDANI, 1791, Testaceographia, Vol. I, Pt. 2, p. 98, Pl. CV, fig. *O*.
Dentalina farcimen REUSS, 1861, Bull. Acad. Roy. Belg., Ser. 2, Tome XV, p. 146, Pl. I, fig. 18.
Nodosaria (D.) farcimen BRADY, 1884, Chall. Rept., Vol. IX, pp. 498, 499, Pl. LXII, figs. 17, 18; woodcuts figs. 13 *a–c*.
Nodosaria farcimen EGGER, 1895, Naturhist. Ver. Passau, Jahresber. XVI, p. 21, Pl. II, fig. 13.

Another species with an extensive geological range, and which was met with in the Older Pliocene of Monte Bartolomeo.

In both samples from California; a few fragments.

Nodosaria soluta *Reuss*.

PLATE XXIX, FIG. 14.

Dentalina soluta REUSS, 1851, Zeitschr. d. deutsch. geol. Gesellsch., Bd. III, p. 60, Pl. III, figs. 4, *a*, *b*.
Nodosaria (D.) soluta BRADY, 1884, Chall. Rept., Vol. IX, pp. 503, 504, Pl. LXII, figs. 13–16. EGGER, 1895, Naturhist. Ver. Passau, Jahresber. XVI, pp. 21, 22, Pl. II, figs. 6, 14, 15. A. WOODWARD, 1898, Journ. N. York Micr. Soc., p. 17.

The specimens of *N. soluta* from California are represented by fragments only. The smaller and neater specimens appear to pass into *N. adolphina*, which latter is here represented by the non-aculeate variety.

It has been previously recorded from the Miocene of an artesian well in Atlantic City, New Jersey, by A. Woodward.

Santa Clara County, California; frequent.

Nodosaria longiscata *d'Orbigny*.

PLATE XXIX, FIG. 15.

Nodosaria longiscata D'ORBIGNY, 1846, Foram. Foss. Vienne, p. 32, Pl. I, figs. 10–12.
Nodosaria arundinea SCHWAGER, 1866, Novara-Exped., geol. Theil, Bd. II, p. 211, Pl. V, figs. 43–45. SHERBORN & CHAPMAN, 1886, Journ. Roy. Micr. Soc., Ser. 2, Vol. VI, p. 747, Pl. XIV, figs. 28, 29.
Nodosaria longiscata BRADY, 1888, Quart. Journ. Geol. Soc., Vol. XLIV, p. 6. CHAPMAN, 1898, Quart. Journ. Geol. Soc., Vol. LIV, p. 554.

Some detached segments of *Nodosaria*, without doubt belonging to the above species, were found in the Californian foraminiferal rock. *N. longiscata* is well known as a species occurring in the Eocene, Miocene and Pliocene formations.

Santa Clara County, California; very rare.

Nodosaria adolphina *d'Orbigny.*

PLATE XXIX, FIG. 16.

Dentalina adolphina D'ORBIGNY, 1846, Foram. Foss. Vienne, p. 51, Pl. II, figs. 18–20. BORNEMANN, 1855, Zeitschr. deutsch. geol. Gesellsch., Bd. VII, p. 324, Pl. XIII, fig. 5. NEUGEBOREN, 1856, Denk. Wiss. Wien, Bd. XII, Pt. 2, p. 88, Pl. IV, figs. 8*a* and *b*.
Nodosaria adolphina SCHWAGER, 1866, Novara-Exped., geol. Theil, p. 235, Pl. VI, figs. 72, 73.
Dentalina adolphina GÜMBEL, 1868 (1870), Abhandl. m.-ph. Cl. k.-bayer. Ak. Wiss., Bd. X, p. 623, Pl. I, fig. 32. SHERBORN & CHAPMAN, 1886, Journ. Roy. Micr. Soc., Ser. 2, Vol. VI, p. 750, Pl. XV, figs. 11*a* and *b*, 12.

This Tertiary foraminifer is here represented by small specimens comparable in form but without the spinose segments which the species exhibits when fully grown.

Santa Clara County, California; frequent.

Nodosaria obliqua *(Linné).*

PLATE XXIX, FIG. 17.

Nautilus obliquus LINNÉ, 1767, Syst. Nat., 12th Ed., pp. 281, 1163; —1788, ibid., 13th (Gmelin's) Ed., p. 3372, No. 14.
Orthocera obliqua LAMARCK, 1822, Anim. sans Vert., Vol. VII, p. 594, No. 4.
Nodosaria obliqua BRADY, 1884, Chall. Rept., Vol. IX, pp. 513, 514, Pl. LXIV, figs. 20–22.

A fragment of an obliquely costate shell was found in the material examined, which appears to belong to the above typical species. It has also been recorded from the Miocene of Norfolk, Virginia.

Santa Clara County, California.

Cristellaria *Lamarck* [1816].

Cristellaria cassis *(Fichtel & Moll).*

PLATE XXIX, FIG. 18.

Nautilus cassis FICHTEL & MOLL, 1798, Test. Micr., p. 95, Pl. XVII, figs. *a–l.*

Cristellaria cassis LAMARCK, 1816, Tabl. Encycl. et Méthod., Pl. CCCCLXVII, figs. 3 *a–d.* D'ORBIGNY, 1825, Tabl. Méth. Céphal., p. 124, No. 3. BRADY, 1884, Chall. Rept., Vol. IX, pp. 552, 553, Pl. LXVIII, fig. 10. FORNASINI, 1893–94, Mem. R. Accad. Sci. Bologne, Ser. 5, Vol. IV, p. 221, Pl. III, figs. 21, 21*a;* p. 222, Pl. III, figs. 22, 23. A. SILVESTRI, 1899, Mem. Accad. Pont. Lincei, Vol. XV, pp. 206–212, Pl. VII, figs. 13–17.

This species is extremely variable and has been described under as many names as its variations. The specimens are very like some figured by Dr. A. Silvestri from the Pliocene of Siena. They are devoid of the beaded ornamentation, are much compressed, and have the sutural margins at the periphery terminating in a point which gives a serrate aspect to the shell-margin.

C. cassis is found in most Tertiary deposits, and at the present time appears to be restricted to fairly shallow deposits of tropical or warm temperate areas.

Santa Clara County, California; common.

Cristellaria miocenica, sp. nov.

PLATE XXX, FIGS. 1 AND 1*a*.

Test subcircular or suboval, much compressed. The sutural lines reflexed; septa thick and swollen on surface. A distinct umbilical depression is observable in nearly all specimens. Average breadth of test, .87 mm.; thickness, .16 mm.

This species most nearly resembles *C. complanata* Reuss,[1] but the latter species is in outline of the *C. crepidula* type, whilst *C. miocenica* belongs to the more discoidal type of *C. rotulata*. The specimen here figured is one of the more lengthened forms.

Santa Clara County, California; common.

[1] Verstein. böhm. Kreidef., 1845–6, Pt. 1, p. 33, Pl. XIII, fig. 54.

Cristellaria arcuata *d'Orbigny.*

PLATE XXX, FIG. 2.

Cristellaria arcuata D'ORBIGNY, 1846, Foram Foss. Vienne, p. 87, Pl. III, figs. 34-36. EGGER, 1857, Neues Jahrbuch für Min., p. 296, Pl. XIV, figs. 28-30. NEUGEBOREN, 1872, Arch. Ver, Siebenbürg. Landeskunde N. F. X (2), p. 276, Pl. I, figs. 3 and 4. HANTKEN, 1875 (1876), Magyar kir. földt. int. évkönyve, Vol. IV, p. 45, Pl. V, figs. 5 and 6; and Mitth. a. d. Jahrb. k. ungar. geol. Anstalt, IV; 1875 (1881), p. 53, Pl. I, figs. 3 and 4. JONES, 1876, M. Micr. Journ., Vol. XV, Pl. 128, figs. 9*a*, *b* and 20*a*, *b*; 21*a*, *b*.

Some very fine examples of the above were found; they are especially characterized by the well developed final chamber. This Tertiary species closely approaches the Cretaceous *C. triangularis* of the same author, if indeed it can be considered a distinct species.

Santa Clara County, California; common.

Cristellaria gibba *d'Orbigny.*

PLATE XXX, FIG. 3.

Cristellaria gibba D'ORBIGNY, 1839, Foram. Cuba, p. 63, Pl. VII, figs. 20, 21. BRADY, 1884, Chall. Rept., Vol. IX, pp. 546, 547, Pl. LXIX, figs. 8, 9.

The specimen here figured is of somewhat irregular growth but without doubt belongs to the above species. Its range in geological time dates from the Cretaceous or even earlier.

Santa Clara County, California; one specimen.

Cristellaria rotulata *(Lamarck).*

PLATE XXX, FIG. 4.

Lenticulites rotulata LAMARCK, 1804, Annales du Muséum, Tome V, p. 188, No. 3.—Tabl. Encycl. et Méthod, Pl. CCCCLXVI, fig. 5.

Cristellaria rotulata PARKER & JONES, 1865, Phil. Trans., Vol. CLV, p. 345, Pl. XIII, fig. 19. BRADY, 1884, Chall. Rept., Vol. IX, pp. 547, 548, Pl. LXIX, figs. 13*a*, *b*.

The specimens under notice are somewhat strongly septate, otherwise they are typical of the species.

The occurrence of *C. rotulata* in the Miocene of America is recorded by A. Woodward as follows:—from artesian wells, Atlantic City and Quinton, New Jersey.

California, from both samples; very common.

Subfamily POLYMORPHININÆ.

Uvigerina *d'Orbigny* [1826].

Uvigerina tenuistriata *Reuss.*

PLATE XXX, FIG. 5.

Uvigerina tenuistriata REUSS, 1870, Sitzungsb. Akad. Wiss. Wien, Bd. LXII, p. 485. SCHLICHT, 1870, Foram. Pietzpuhl, Pl. XXII, figs. 34-36. BRADY, 1884, Chall. Rept., Vol. IX, p. 574, Pl. LXXIV, figs. 4-7. BAGG, 1898, Bull. Am. Palæont., Vol. II, No. 10, pp. 326, 327.

This species was originally described from the Septaria-clay of Pietzpuhl. In recent deposits it occurs in fairly shallow water. It has been recorded from the Miocene of America by Dr. Bagg, who found it at Norfolk, Virginia, and also in material, probably of the same age, from an artesian well at Crisfield, Maryland.

Santa Clara County, California; rare.

Family GLOBIGERINIDÆ.

Pullenia *Parker & Jones* [1862].

Pullenia sphæroides *(d'Orbigny).*

PLATE XXX, FIG. 6.

Nonionina sphæroides D'ORBIGNY, 1826, Ann. Sci. nat., Tome VI, p. 293, No. 1, Modèle, No. 43.

Nonionina bulloides, id., ibid., p. 293, No. 2. Id., 1846, Foram. Foss. Vienne, p. 107, Pl. V, figs. 8-10.

Pullenia sphæroides CARPENTER, 1862, Introd. Foram., p. 184, Pl. XII, fig. 12. BRADY, 1884, Chall. Rept., Vol. IX, pp. 615, 616, Pl. LXXXIV, figs. 12, 13. JONES, 1896, Monogr. Foram. Crag, Pt. III, pp. 286-288, Pl. II, (Pt. II, 1895), figs. 31, 32.

The range of this species commences with the Cretaceous, and it is frequent in many deposits of Miocene age.

Santa Clara County, California; frequent.

Pullenia multilobata, sp. nov.

PLATE XXX, FIGS. 7 AND *7a*.

The test bears a general resemblance to *P. quinqueloba* Reuss, but is more compressed and has the sutural lines only faintly marked. Its chief distinction is the larger number of chambers visible on the last whorl; in the case of the specimen figured there are nine, and consequently these are narrower than those of *P. quinqueloba*. Width of test, 1 mm.; thickness, .5 mm.

Santa Clara County, California; very rare.

Family ROTALIIDÆ.

Subfamily ROTALIINÆ.

Discorbina *Parker & Jones* [1862].

Discorbina allomorphinoides *(Reuss)*.

PLATE XXX, FIG. 8.

Valvulina allomorphinoides REUSS, 1860, Sitzungsb. Akad. Wiss. Wien, Vol. XL, p. 223, Pl. XI, fig. 6.
Discorbina allomorphinoides BRADY, 1884, Chall. Rept., Vol. IX, p. 654.

This interesting species was found by Reuss in the Cretaceous of Westphalia. Its present occurrence helps to complete its range in time, since it was also found by Brady in recent deposits at three stations and at depths from 10 to 155 fathoms.

The specimens from California in some respects resemble *Pulvinulina hanerii* d'Orb., sp., but the test is coarser and bears stronger affinities towards *Discorbina*.

California, from both samples; very abundant.

Anomalina *d'Orbigny* [1826].

Anomalina grosserugosa *(Gümbel)*.

PLATE XXX, FIG. 9.

Truncatulina grosserugosa GÜMBEL, 1868, Abhand. d. k. bayer. Akad. Wiss., m.-ph. Cl., Vol. X, p. 660, Pl. II, fig. 104 *a*, *b*.
Anomalina grosserugosa SHERBORN & CHAPMAN, 1889, Journ. Roy. Micr. Soc., p. 487, Pl. XI, fig. 34.

A well known Tertiary species; this form has been previously noted by A. Woodward from artesian well borings at Atlantic City, Quinton and Beach Haven, in New Jersey.

A. grosserugosa is somewhat difficult to separate from *Nonionina umbilicatula*, inasmuch as the aperture is not always a safe distinction, for the obliquely apertured Anomalines pass insensibly into the symmetrical Nonionine forms. *A. grosserugosa* is perhaps coarser in shell structure and has its chambers more strongly inflated than *N. umbilicatula*.

Santa Clara County, California; frequent.

Anomalina rotula *d'Orbigny.*

PLATE XXX, FIG. 10.

Anomalina rotula D'ORBIGNY, 1846, Foram. Foss. Vienne, p. 172, Pl. X, figs. 10–12.
Planorbulina rotula SHERBORN & CHAPMAN, 1886, Journ. Roy. Micr. Soc., Ser. 2, Vol. VI, p. 757, cut in text No. 155. TERRIGI, 1889, Mem. Accad. Lincei; Ser. 4, Vol. VI, p. 116, Pl. VII, fig. 4.

This species by gradational forms appears to pass into *Truncatulina ungeriana* d'Orb., sp. It is well known as an Eocene and Miocene fossil.

Santa Clara County, California; frequent.

Truncatulina *d'Orbigny* [1826].

Truncatulina pygmæa *Hantken.*

PLATE XXX, FIG. 11.

Truncatulina pygmæa HANTKEN, 1875, Mittheil. Jahrb. d. k. ung. geol. Anstalt, Vol. IV, 1881, p. 78, Pl. X, fig. 8. BRADY, 1884, Chall. Rept., Vol. IX, pp. 666, 667, Pl. XCV, figs. 9 and 10.

This species was found in the Oligocene of Hungary, and in deposits at the present day at considerable depths.

California, in both samples; very common.

Rotalia *Lamarck* [1804].

Rotalia orbicularis *d'Orbigny.*

PLATE XXX, FIG. 12.

Rotalia (Gyroidina) orbicularis D'ORBIGNY, 1826, Ann. Sci. nat., Vol. VII, p. 278, No. 1, Modèle, No. 13.
Rotalia orbicularis BRADY, 1864, Trans. Linn. Soc. Lond., Vol. XXIV, p. 470, Pl. XLVIII, fig. 16. Id., 1884, Chall. Rept., Vol. IX, p. 706, Pl. CVII, fig. 5; Pl. CXV, fig. 6.

The range of *R. orbicularis* is throughout the Tertiary formations.

It occurs in the Miocene of Southern Italy and of Norfolk, Virginia, and in the Older Pliocene of Monte Bartolomeo.

California, in both samples; common.

Subfamily POLYSTOMELLINÆ.

Nonionina *d'Orbigny* [1826].

Nonionina communis *d'Orbigny.*

PLATE XXX, FIG. 13.

Nonionina communis D'ORBIGNY, 1826, Ann. Sci. nat., Vol. VII, p. 294, No. 20. Id., 1846, Foram. Foss. Vienne, p. 106, Pl. V, figs. 7 and 8.

Amongst other occurrences this species has been recorded from the Older Pliocene of Monte Bartolomeo.

Santa Clara County, California; frequent.

Nonionina boueana *d'Orbigny.*

PLATE XXX, FIGS. 14 AND 14*a*.

Nonionina boueana D'ORBIGNY, 1846, Foram. Foss. Vienne, p. 108. Pl. V, figs. 11 and 12. BRADY, 1884, Chall. Rept., Vol. IX, p. 729, Pl. CIX, figs. 12 and 13.

The specimens here figured are very pretty and extreme variations of the type, having the thickened sutures very distinct, the peripheral edge sharp, and the septal face with limbate edges.

N. boueana has been previously recorded from the Miocene of Norfolk, Virginia.

California, in both samples; very common.

Nonionina umbilicatula *(Montag.)*.

PLATE XXX, FIG. 15.

Nautilus umbilicatulus MONTAGU, 1803, Test. Brit., p. 191; Suppl., p. 78, Pl. XVIII, fig. 1.
Nonionina soldanii D'ORB., 1846, Foram. Foss. Vienne, p. 109, Pl. V, figs. 15, 16.
Nonionina umbilicatula BRADY, 1884, Chall. Rept., Vol. IX, p. 726, Pl. CIX, figs. 8, 9.

This is a Tertiary species, and it has been noted, amongst other occurrences, from the Older Pliocene of Monte Bartolomeo (under the name of *N. soldanii*).

California, in both samples; frequent.

Nonionina pompilioides *(Fichtel & Moll)*.

PLATE XXX, FIGS. 16 AND 16*a*.

Nautilus pompilioides FICHTEL & MOLL, 1798, Test. Micr., p. 31, Pl. II, figs. *a–e*.
Nonionina umbilicata D'ORBIGNY, 1826, Ann. Sci. nat., Vol. VII, p. 293, Pl. 15, figs. 10–12, No. 5, Modèles, No. 86.
Nonionina pompilioides BRADY, 1884, Chall. Rept., Vol. IX, p. 727, Pl. CIX, figs. 10, 11.

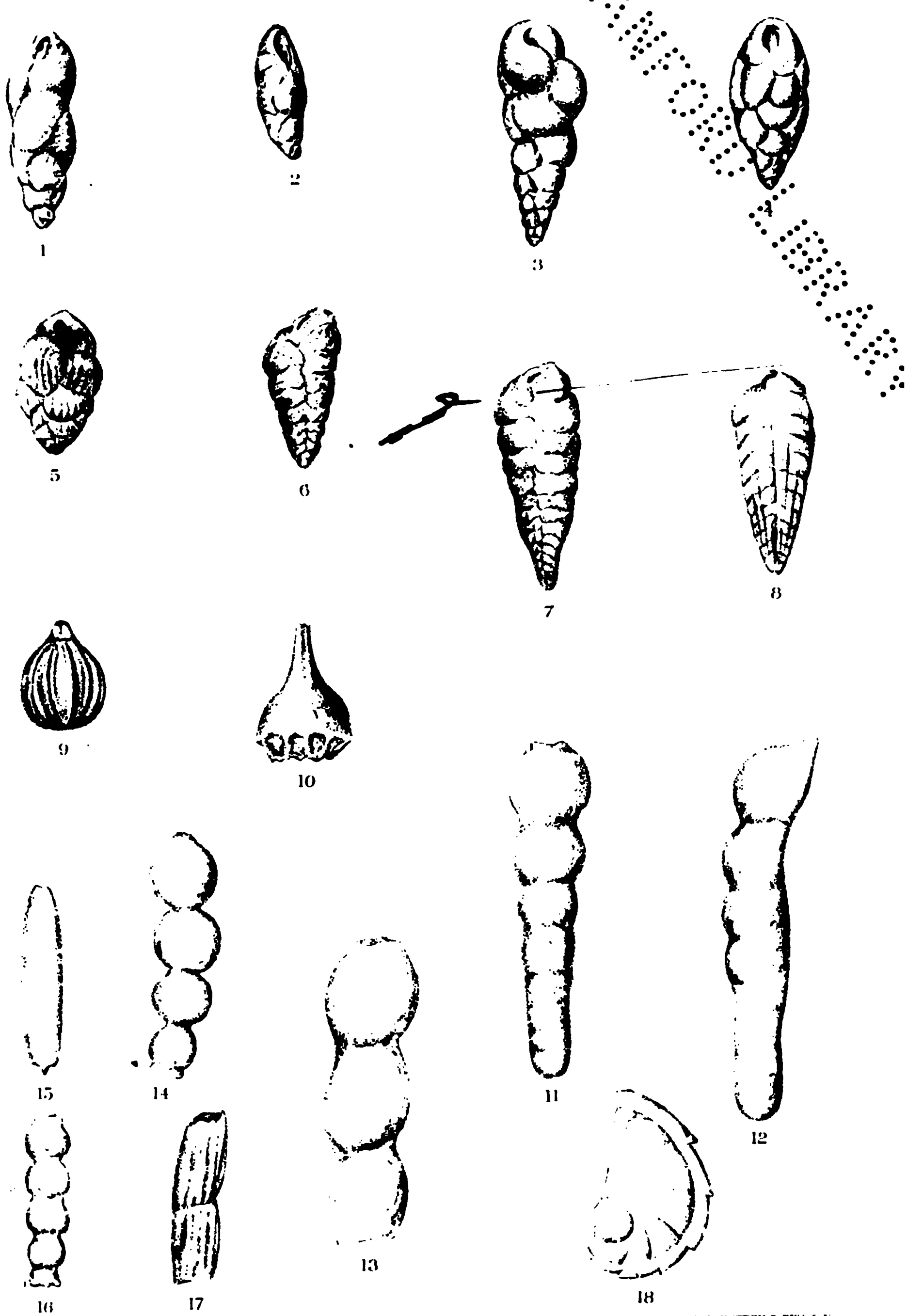
The specimens from California are very typical examples, with a broad terminal septal face.

Santa Clara County, California; rare.

EXPLANATION OF PLATE XXIX.

Figs. 1-10 forty-five times enlarged; 11-17 thirty times enlarged; 18 twenty times enlarged.

Fig. 1. *Bulimina elongata* D'ORB.
Fig. 2. " *elegantissima* D'ORB.
Fig. 3. " *elegans* D'ORB.
Fig. 4. " *affinis* D'ORB.
Fig. 5. " *buchiana* D'ORB.
Fig. 6. *Bolivina dilatata* REUSS.
Fig. 7. " " var. *angusta* EGGER.
Fig. 8. " *ænariensis* (COSTA).
Fig. 9. *Lagena sulcata* (W. & J.).
Fig. 10. " *crenata* P. & J.
Fig. 11. *Nodosaria radicula* (L.).
Fig. 12. " *pauperata* D'ORB.
Fig. 13. " *farcimen* REUSS.
Fig. 14. " *soluta* REUSS.
Fig. 15. " *longiscata* D'ORB.
Fig. 16. " *adolphina* D'ORB.
Fig. 17. " *obliqua* (L.).
Fig. 18. *Cristellaria cassis* (F. & M.)



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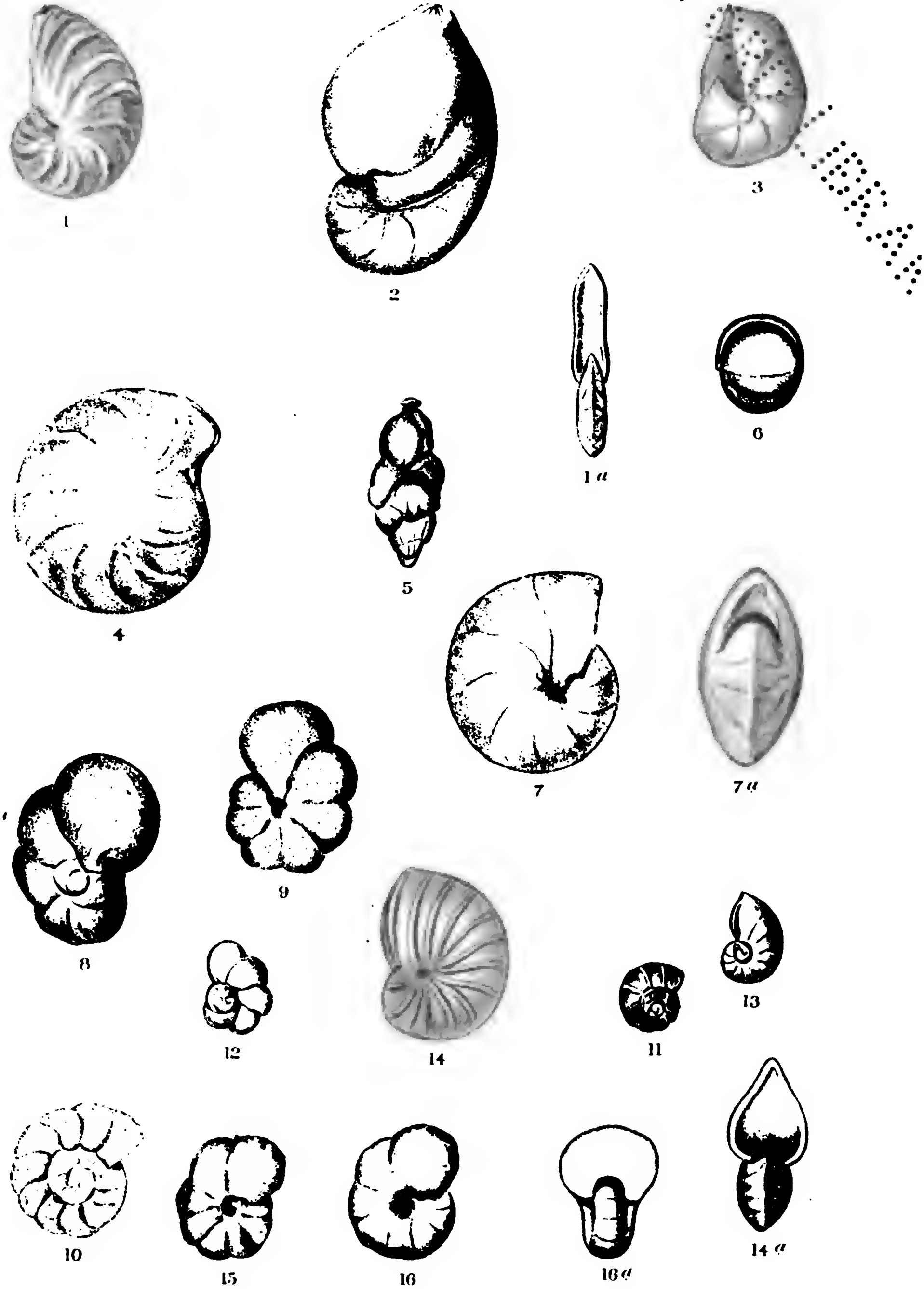
EXPLANATION OF PLATE XXX.

All the figures are thirty times enlarged.

Figs. 1 and 1*a*. *Cristellaria miocenica*, sp. nov.
Fig. 2. " *arcuata* D'ORB.
Fig. 3. " *gibba* D'ORB.
Fig. 4. " *rotulata* (LAM.).
Fig. 5. *Uvigerina tenuistriata* REUSS.
Fig. 6. *Pullenia sphæroides* (D'ORB.).
Figs. 7 and 7*a*. *Pullenia multilobata*, sp. nov.
Fig. 8. *Discorbina allomorphinoides* (REUSS).
Fig. 9. *Anomalina grosserugosa* (GÜMBEL).
Fig. 10. " *rotula* D'ORB.
Fig. 11. *Truncatulina pygmæa* HANTKEN.
Fig. 12. *Rotalia orbicularis* D'ORB.
Fig. 13. *Nonionina communis* D'ORB.
Figs. 14 and 14*a*. " *boueana* D'ORB.
Fig. 15. " *umbilicatula* (MONTAG.).
Figs. 16 and 16*a*. " *pompilioides* (F. & M.).



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The Pleistocene Geology of the South Central Sierra Nevada with Especial Reference to the Origin of Yosemite Valley

BY

HENRY WARD TURNER

WITH NINE PLATES

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THE PLEISTOCENE GEOLOGY OF THE SOUTH CENTRAL SIERRA NEVADA WITH ESPECIAL REFERENCE TO THE ORIGIN OF YOSEMITE VALLEY.

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PLATES XXXI–XXXIX.

 November 3, 1900.

I. THE PRE-PLEISTOCENE OROGENIC HISTORY OF THE SIERRA NEVADA.

IN THE Sierra Nevada, folding and lateral thrust movements appear to have culminated about the close of the Jurassic, and this may likewise have been the case in the Great Basin. Professor Whitney[1] regarded this time as preeminently the mountain-building epoch of the region west of the Wasatch. The Sierra may thus be said to have first existed as a great mountain range in early Cretaceous time. This Jurassic range, as well as the Jurassic and older ranges of the Great Basin, was greatly eroded during Cretaceous and Tertiary time; and we may then picture this entire region from the Pacific Ocean eastward as being in middle Tertiary time characterized by low ridges with broad basins often occupied by extensive lakes.[2] It should here be noted, however, that some of these basins may have been formed by subsidence along normal faults in early Tertiary time, as suggested by King and Lindgren. The orogenic disturbances of post-Miocene time have displaced these Tertiary lake beds at many places. Considerable areas have been eroded, and still larger areas are covered by Pleistocene deposits. Patches of them, and often extensive areas are, however, still to be found. Examples of such deposits are the Pah-Ute beds of north-central Oregon; the Mohawk Valley and Boca-Truckee Valley beds of the eastern Sierra Nevada; the Tertiary beds, mainly of volcanic detritus, of Carson Valley;[3] the Eocene or Miocene beds (Esmeralda Formation)[4] of Esmeralda County, Nevada; and the Tertiary beds of the Mojave and Colorado deserts.

There appears to be a good basis for the hypothesis of Le Conte, that the whole region from the Wasatch to the Sierra was uplifted into a great arch, and that the valleys

[1] Auriferous Gravels, 1880, p. 315.

[2] See Whitney's Climatic Changes, 1882, pp. 114-115.

[3] Journ. Geol., Vol. IV, 1896, p. 900.

[4] Amer. Geol., Vol. XXV, 1900, pp. 168-170.

and ridges of the Great Basin are the result of displacements along normal faults of sections of this broad arch Gilbert[1] was, however, the first to elucidate the structure of the Basin Ranges. He found little evidence, except in the Inyo Mountains and the Sierra Nevada, that there had previously been a period in which the rocks had been folded and crushed and ranges formed by lateral pressure. It is, however, possible that such ranges are much more abundant in the fortieth parallel region than in the districts to the south, where most of Mr. Gilbert's observations were made. Clarence King[2] apparently states the case fairly for the fortieth parallel belt as follows:—

> The frequency of these monoclinal detached blocks gives abundant warrant for the assertions of Powell and Gilbert, that the region is one prominently characterized by vertical action; yet when we come to examine with greater detail the structure of the individual mountain ranges, it has seemed that this vertical dislocation took place after the whole area was compressed into a great region of anticlinals with intermediate synclinals. In other words, it was a region of enormous and complicated folds, riven in later time by a vast series of vertical displacements which have partly cleft the anticlinals down through their geological axes and partly cut the old folds diagonally or perpendicularly to their axes.

The Sierra Nevada and some of the ranges of the Great Basin thus appear to have had a common orogenic history.

So much has been written about the normal faults of the Great Basin that extended discussion of them here is unnecessary. There is, however, some difference of opinion as to the amount of this faulting and the time at which the main faults were formed. The greatest fault-scarp of the region under discussion is probably that of the east face of the Sierra Nevada. This scarp is supposed by Le Conte[3] to have been formed at the close of the Tertiary. Lindgren[4] thinks that the first faulting separating the Sierra Nevada from the interior basin occurred before the deposition of Chico-Cretaceous, but supposes that vigorous faulting occurred along the same fracture at various times

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[1] Wheeler Survey Reports, Vol. III, 1875, pp. 21-42.

[2] Fortieth Parallel Reports, Vol. I, 1878, p. 735. See, also, Russell, Monograph XI, U. S Geol. Surv. on Lake Lahontan, 1885, p. 26.

[3] University Chronicle, Berkeley, California, Vol. I, 1898, p. 481.

[4] Journ. Geol. Vol. IV, 1896, p. 894.

subsequently. King[1] supposes that the fault-scarp of the Sierra Nevada was formed either within the Eocene, or at the close of the Eocene time, and was the direct cause of the subsidence of the area which was soon after occupied by the Miocene Pah-Ute Lake.[2] King,[3] however, also states "that in Post-Pliocene times a very great orographical movement has taken place, the maximum displacement being upon two lines: one upon the eastern base of the Sierra Nevada, a region of long previously defined fault; the other upon the western base of the Wasatch, also a region of recurrent faults."

The main Sierra Nevada fault-scarp is nearly continuous from the south end of the range to Honey Lake. The rocks forming this scarp are to a very large extent granitic in character with subordinate amounts of schists of sedimentary and igneous origin; but the entire series is of pre-Cretaceous age. The remarkably fine scarp west of Honey Lake appears to have been formed in late Tertiary or early Pleistocene time, according to the investigations of Mr. Diller; for at Thompson Peak and at other points on the brink of the fault-scarp there are approximately horizontal beds of Tertiary tuffs, and to the northwest of Thompson Peak there is an extensive series of Neocene gravels still preserved, resting at some points on the brink of the fault-scarp. Lying to the west of this main fault-zone is another of lesser magnitude extending from Lake Tahoe to American Valley, in Plumas County. This fault was studied by Lindgren at Lake Tahoe and by myself at Sierra Valley and American Valley. James Mills[4] also calls attention to this line of faulting, one portion of which he designates as the "Cromberg fault."

The basin of Lake Tahoe is regarded by Lindgren[5] as being a portion of a depressed block dropped down along a double fault. This fault valley formerly extended from

[1] Fortieth Parallel Reports, Vol. I, 1878, p. 744.

[2] Fortieth Parallel Reports, Vol. I, 1878, p. 442.

[3] This lake occupied a portion of the Great Basin east of the Cascade Range, and King appears to consider that the Cascade Range was likewise separated from the Great Basin by faulting along the same zone as that of the Sierra Nevada fault-scarp.

[4] Bull. Geol. Soc. Amer., Vol. III, 1892, pp. 418, 419.

[5] Journ. Geol. Vol. IV, 1896, p. 895 See also Truckee folio, U. S. Geol. Surv.

Lake Tahoe to Sierra Valley, and all that portion of this valley from the north end of Lake Tahoe to Sierra Valley is filled with Tertiary lavas, and north of Boca there are Neocene lake beds, so that Lake Tahoe may be said to be a dammed-up canyon or valley. Lindgren also found evidence[1] that the Tertiary crest-line of the Sierra Nevada was approximately in the same place that it now is in the Lake Tahoe region, and that the Neocene rivers studied by him headed near where the corresponding modern rivers now begin, in a region of lofty peaks and ridges. Moreover, the Tertiary lavas that came out of volcanoes along the crest of the range in this region flowed both east and west, also indicating that the crest-line at the time of these eruptions was approximately where it now is. These facts, taken in connection with the apparent existence of a fault basin at Lake Tahoe before the time of the lava flows, seem clearly to point to faulting in this region in early Miocene time.

Where this fault was examined by myself in the vicinity of Mohawk Valley, the evidence tends to show that there the faulting was after the period of the deposition of the Neocene gravels. On the edge of the plateau west of Mohawk Valley there are river gravels of Tertiary age lying on the brink of the fault-scarp. It is evident that the river which deposited these gravels could not have existed after the fault-scarp formed. These gravels are quite the same as other river gravels, to which Professor Knowlton has assigned an upper Miocene age on the basis of the fossil flora; hence, the faulting here would seem to be post-Miocene. Nevertheless, in Mohawk Valley, which was formed by the subsidence of the area to the east of the fault-scarp, there are Neocene lake-beds, showing the existence of a basin there in Tertiary time; and these beds show no signs of disturbance, lying horizontally at all points, so far as noted, except along a recent fault-line, which lies on the east side of the valley, and not on the west, where the older faulting occurred. If these Neocene

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[1] Bull. Geol. Soc. Amer. Vol. IV, 1893, pp. 257-298.

lake beds were deposited before the fault formed, they must have undergone a subsidence of 2,000 feet without being tilted or dislocated, except along the immediate line of faulting, which erosion has no doubt long since removed.

Owen's Valley has been said to be a post-Tertiary fault valley, but to the south of Owen's Lake there are beds which dip west at a gentle angle, and through these beds the stream which formed the outlet of Owen's Lake at an

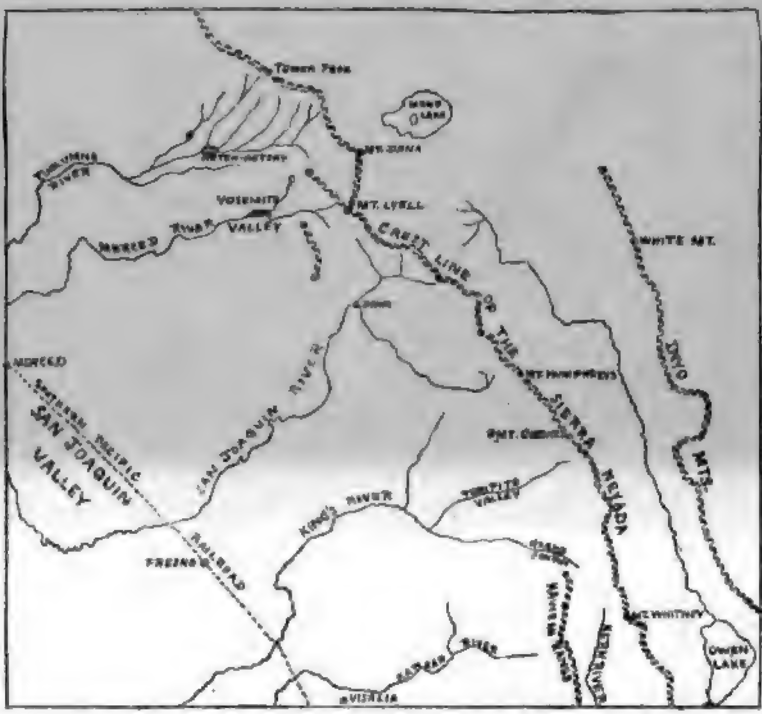

FIG. 1.—Sketch map of the south-central Sierra Nevada.

earlier period has cut a channel. These beds in their upper portions are largely made up of rhyolite tuffs, but at their base are seen shales and conglomerates composed of ordinary sediments, the series strongly resembling Tertiary beds as seen at other points. There then appears to have been a basin here in Tertiary time. The west border of this basin is presumed to have been the Jurassic Sierra Nevada,

formed by folding, and probably at this time much worn down; but that the fault-scarp of this portion of the range was initiated previous to the deposition of these beds seems not improbable.

In the south-central Sierra Nevada there is also some evidence tending to show that the crest-line of the range was in Tertiary time where it now is. Thus the gravel deposits of the Tertiary Tuolumne River have been traced from the foothills to Mt. Dana, the course of the stream substantially coinciding with that of the present Tuolumne taken in a general way, as will be more fully noted hereafter. There is, also, some evidence that the Pleistocene canyons of the southern Sierra are the greatly deepened valleys of Tertiary time, and these Tertiary valleys show every evidence of ending west of the present crest of the Sierra.

II. OROGENIC MOVEMENTS IN THE PLEISTOCENE.

For the sake of convenience, the orogenic disturbances are treated of in one section, although they probably occurred at various times and in each of the subdivisions of the Pleistocene.

From the preceding section it will be seen that the main displacements are regarded as having occurred within and at the close of the Tertiary Period. Until the geology of the eastern slope of the Sierra Nevada is better known it will not be possible to estimate to what extent such displacements have occurred within Pleistocene time. Mr. Walcott[1] has brought forward good evidence to show that in the neighborhood of Big Pine, the Inyo Mountains, the range lying immediately east of the southern Sierra Nevada has undergone an elevation in Pleistocene time of 3,000 feet. This elevation probably occurred during the middle of Pleistocene time, as the lake beds of the Waucoba embayment southeast of Big Pine are regarded by Mr. Walcott as probably of early Pleistocene age. It may have occurred

[1] Journ. Geol., Vol. V, 1897, pp. 340–348.

before the close of the Glacial epoch, for on the east side of White Mountain, near the north end of the Inyo range, there is evidence that the upper parts of the canyons were occupied by glacial ice and it seems unlikely that glaciers could have existed there when the range was 3,000 feet lower.[1] That a movement of such magnitude should not also have affected the Sierra Nevada lying immediately west is improbable. Positive evidence of comparatively recent displacements along the east slope of the Sierra has been adduced by several observers. Turner[2] notes a displacement on the east side of Mohawk Valley said to have occurred in 1876; Lindgren[3] describes recent faulting along the line of the Central Pacific Railroad at Verdi, and to the southeast of Lake Tahoe to the west of Genoa; Russell[4] refers to a fault just northwest of Mono Lake cutting a moraine, and hence post-glacial. The displacements formed at the time of the earthquake of 1872 in Owen's Valley, chiefly along the west side, furnish further evidence in the same line. The destruction of life and property was greatest at Lone Pine, not far from Owen's Lake; here many people were killed or injured. The shaking of the ground continued at intervals for many days after the strongest shocks. South of Lone Pine a line of poplar trees entirely disappeared. Just northeast of Owen's Lake is a small basin which is said to have been formed at the time of the earthquake. It was occupied by water for some time, but is now dry. Extending from this dry lake to Lone Pine is a terrace-like embankment produced by the subsidence of a narrow strip of land, and this subsided strip now contains pools of water, while considerable portions of it form meadow-land. This earthquake seems clearly to have resulted from a slip along the great fault of the Sierra.

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[1] In the Silver Peak Range, lying just east of the Inyo Mountains, there is no evidence of the former existence of glaciers. The Silver Peak Range attains an altitude of 9,500 feet.

[2] Bull. Phil. Soc. Washington, Vol. XI, 1891, p. 396; and Downieville folio, U. S. Geol. Surv.

[3] Journ. Geol., Vol. IV, 1896, pp. 898-899.

[4] Eighth Annual Rept. U. S. Geol. Surv., Part I, 1889, p. 389.

III. PLEISTOCENE PERIODS.

1. *The Sierran Period.*—A period of extensive erosion and canyon cutting, probably occupying the larger part of the early Pleistocene, and greater than all the remainder of post-Tertiary time. This may be called, following Le Conte, the Sierran Period.

2. *The Glacial Period.*

3. *The Recent or Post-Glacial Period.*[1]—This may also be called the human period, since whatever the time of the appearance of man on the earth, he first reached an advanced status at this time.

1. The Sierran Period.

It has long been recognized[2] that the period of canyon cutting of the Sierra was a very long one. Recently Hershey[3] has proposed to designate this time of erosion as the Ozarkian Period. Professor Joseph Le Conte[4] has laid stress on the long duration of the Ozarkian Period in the Sierra Nevada, and suggests that inasmuch as the term "Ozarkian" has been used by Broadhead for a Lower Silurian series in the Ozark region, the term "Sierran," in place of "Ozarkian," be used for this early Pleistocene period of erosion. Undoubtedly a large part of the materials filling the Great Valley of California and those forming the older alluvial fans of the Great Basin were deposited at this time, and the enormous amount of these detrital masses, as well as the tremendous canyons of the Sierra, make it probable that the Sierran Period comprises the larger part of post-Tertiary time.

2. The Glacial Period.

That a large portion of the higher Sierra was formerly covered by a vast field of ice and snow is patent to every

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[1] Many geologists do not include the Recent Period in the Pleistocene. It has been the custom, however, of the U. S. Geological Survey to relegate all time from the close of the Pliocene to the present or historic period to the Pleistocene.

[2] See "Description of Gold Belt" in the folios of the Sierra Nevada, U. S. Geol. Surv.; also Journ. Geol., Vol. IV, 1896, p. 900.

[3] Science, Vol. III, 1896, p. 620.

[4] Journ. Geol. Vol. VII, 1899, p. 525.

observer. It is commonly stated that the glaciation of the Sierra Nevada appears to have been much more recent than in the northern United States. This seems proven by the fresh appearance of some of the moraines and the excellent preservation of the glacial polish high up in the canyons. Until recently, but little attention has been paid to the oldest moraines which occur far down on the flanks of the range and which have been so greatly weathered and covered by vegetation as not to readily attract attention. Moreover, the rocks that lie within the glaciated area near these old moraines never show glacial markings, and are often disintegrated in spots to the depth of twelve to sixteen feet. Yet it is reasonable to suppose that these rocks were hard and ice polished at the time when they were covered with ice. The etching of the granitic pebbles in the Big Meadow moraines west of Yosemite Valley also indicates a considerable age, as was first pointed out by Professor Branner. There appears to be no difference, so far as one can judge, between the age of these moraines, as indicated by the amount of weathering displayed, and those of the great continental glacier. When the great glacier of the northern United States retreated, it left a great series of terminal moraines extending across the country to the south of the Great Lakes from Long Island through northern Montana, Idaho, and Washington to the Pacific Ocean.[1] The oldest moraines of the Sierra Nevada may possibly be of the same age as the oldest moraines of this continental glacier, The most recent moraines left by the great glacier in its retreat would, of course, be found further to the north, and it is with these moraines and the corresponding glacial markings that the freshest moraines and markings of the Sierra Nevada should be compared.

It is still held by John Muir and others that the canyons of the Sierra were cut out by the action of ice. Some writers consider that deep and narrow canyons of certain types are necessarily the work of ice whether evidence of

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[1] This terminal moraine is said, however, to represent the second great advance of the continental ice sheet.

glacial action other than form exists there or not. This is practically to deny that such canyons could be formed by the action of water in a region which had been subjected to great uplift. The existence of hanging valleys[1] is sometimes considered an evidence of ice action, but if we picture the Sierra Nevada as being a region greatly worn down, so that the physiographic forms were those characteristic of an old topography, and then sharply uplifted as was probably the case, the streams would certainly cut narrow and deep canyons, and many of the earlier small shallow valleys draining into these canyons would form hanging valleys, the whole work being purely that of water and weather. If we suppose the deep, narrow canyons of the southern Sierra below the known limit of glacial action to be dug out by ice, we must likewise ascribe to the northern canyons of the Sierra, some of which are nearly as deep, the same origin, for the entire range has been subjected to the same influences. Take for example the canyon of the North Fork of the Feather River. There is no evidence that any portion

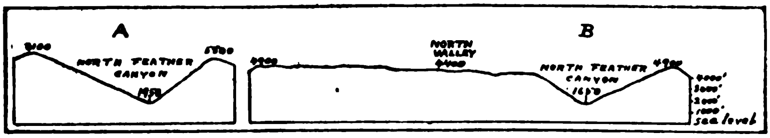

Fig. 2.—Cross-sections of the canyon of the North Fork of the Feather River.
***A.*—West of Buck's Mt. *B.*—Two miles north of Bear Ranch Hill.**

of the canyon of this river, in the area of the Bidwell Bar quadrangle, ever contained glacial ice; yet the canyon is nearly a mile deep at one point and a number of the tributary streams tumble down into it over escarpments from hanging valleys lying above. Moreover, the general form of this canyon, which along here is almost entirely in granitic rock, does not differ greatly from that of some of the canyons farther south, which have been occupied by the ice. Small glaciers did exist on the sumit of the plateau in the Bidwell Bar quadrangle to the east and west of the canyon of the North Feather, but they were of the hanging

[1] **Valleys on plateaus near escarpments.**

type and there is no evidence that they ever extended into the canyon below. If we admit that the canyon of the North Feather was cut out by ice, we must also admit that it was at such a remote period that no remains of any moraines left by the ice exist at the present time. This makes the case improbable inasmuch as moraines could hardly fail to be left in the foothill region or on some of the level topped spurs that border the canyon.

Some evidence will be hereafter presented which suggests that the Glacial Period began in the Sierra before the canyons were cut to their present depth. In other words, the Sierran and Glacial Periods overlapped; but, taken in a general way, it may be stated, with some confidence, that the Glacial Period in the main followed the Sierran Period of erosion. There is apparently positive evidence as to this sequence in Sawmill Canyon, lying northwest of Independence, Inyo County. Sawmill Creek rises upon the east side of the summit line of the Sierra Nevada and cuts through the east steep escarpment to the plains below. After the canyon was cut by the stream there occurred a volcanic outburst, and the lava from this source flowed down the canyon. This lava is of the same kind and probably of exactly the same age as the lava of the little cinder-cones and lava flows which lie along the east base of the range between Independence and Big Pine. These cinder-cones still retain their original contours and are, without much doubt, of middle Pleistocene age. After the flow of lava in Sawmill Canyon took place, the glacier of the canyon reached its maximum, and the largest and apparently the oldest moraine of Sawmill Canyon lies mostly on top of this flow. At Mono Valley, and in some other smaller valleys to the south, the glaciers of the Sierra Nevada protruded as tongues out into the valleys and left beautifully formed moraines on their retreat. In no portion of Owen's Valley, from Big Pine to Owen's Lake, did the glaciers ever extend on to the detrital slopes, much less to the level of the main valley. So far as present evidence goes, if we believe these canyons to be cut by glaciers, we must suppose that the

moraines carried out by the ice have been completely worked over into other physiographic forms, so as to be no longer recognizable as moraines.

We have here, however, enormous alluvial fans clearly the result of water action; and these fans contain approximately sufficient material to fill up the canyons from the degredation of which they were formed, and are in themselves sufficient proof, as it seems to me, that the canyons of the east slope of the Sierra were cut out by water action.

The amount of morainal material in these canyons is insignificant as compared with the amount of material in the alluvial fans which proceed from them. The same may be said of the much larger canyons of the western slope, the detrital materials of which are plainly spread by water action in the Great Valley.

Glaciation of the Inyo Mountains and of the Southern Sierra Nevada.—The precipitation at the present time in the Inyo Mountains is extremely low, probably not over five inches in the southern part of the range and not exceeding fifteen inches on White Mountain, near the northern end. These extremes are merely estimated, no exact records having been kept in the range itself. However, at Independence, in Owen's Valley, a record has been kept, partly by the surgeons of the U. S. Army and partly by the Weather Bureau.[1] The extremes of the rainfall from 1865 to the present time, so far as the records indicate, are 21.63 inches for 1867 and 1.12 inches for 1869, the average for twelve years being 6.1 inches. The estimated small precipitation in the Inyo Mountains, when taken in connection with the great elevation of the range, White Mountain being about 14,200 feet high, is remarkable. The adjacent portions of the Sierra which reach this altitude have a precipitation several times as great. So far as known there has not been observed up to the present time any evidence of the former existence of glaciers in the Inyo Mountains.

[1] I am indebted to Prof. Willis L. Moore, Chief of the Weather Bureau, for a table of the precipitation at Independence.

In September, 1899, a short trip was made among the spurs of the east side of White Mountain and nearly positive evidence obtained, from the shape of the canyons and the heaps of the moraine-like material, of the former existence of glaciers about this peak. The moraines, however, were seen only from a distance. The ice does not appear to have extended below an estimated altitude of about 8,000 feet. In the Sierra Nevada at a corresponding altitude and latitude the glaciers extended much lower.

The storms of the Sierra Nevada and the Inyo Mountains at the present time come largely from the southwest. There must be excepted from this the summer thunder showers, which in the Great Basin are ordinarily called cloud bursts. They are extremely local in character, often raining heavily at one or more points within an area of one hundred square miles, the adjacent region receiving no precipitation at that particular time. As a consequence of the storm clouds coming from the southwest, the atmosphere is largely bereft of its moisture by the first high ridge, which is the Sierra Nevada, leaving but little for the Inyo Range lying next east. The fact of the small development of glacial phenomena in the Inyo Mountains relatively to the Sierra Nevada in the same latitude would seem to suggest that in glacial times, as at present, the climate of the Inyo range was a dry one relatively to that of the Sierra Nevada.

Goodyear,[1] in a description of the southern Sierra Nevada, detected no evidence of glacial markings or of moraines anywhere in the region from Mt. Whitney south. Considering the general accurateness of the observations of Mr. Goodyear, this is somewhat remarkable. The old Hockett trail which was used by Goodyear in his exploration of this region crosses several large moraines, and the new trail to Mt. Whitney[2] passes over as typical moraines as may be seen anywhere in the world. Glacial markings and polish are very clear on the rocks forming the walls of the canyons which extend west from Mt. Whitney, and

[1] Proc. Cal. Acad. Sci., Vol. V, 1875, pp. 180–183.

[2] This trail leaves the Hockett trail west of Cottonwood Creek, passes over into Whitney Meadows, and thence takes a northerly course across Rock Creek to Crabtree Creek, which it follows up east to the west base of Mt. Whitney.

there are the usual rock-basin and morainal lakes and morainal meadows. No evidence was obtained in my trip to Mt. Whitney of the glaciers having extended in the canyons of Cottonwood and Whitney creeks to a lower altitude than 9,000 feet, but no careful examination was made. In Crabtree and Rock creeks, however, which drain west from the crest of the range, the glaciers probably extended farther down. The reason of this small development of the glaciers in the Mt. Whitney region, considering the great altitude, is doubtless in part the low latitude and in part the great height (14,000 feet) of the Kaweah Peak range lying to the west, which receives the first and probably the heaviest precipitation from the rain clouds.

3. The Recent or Post-Glacial Period.

Since the glaciers have vanished from the range its topography has been but slightly modified. The glacial lake basins are being filled up by sediments, frost and heat have continued their work of disintegration, and minor earth movements have taken place as noted under "Orogenic Movements in the Pleistocene." Land slides have occasionally blocked up the canyons, as at one point near the headwaters of the Kern River, and in Slide Canyon which drains into the canyon of the Tuolumne from the north.

Perhaps the most striking evidence of heat and frost erosion in recent times is the formation of talus slopes, and the removal of glacial polish from the rocks. The formation of the rich bottom lands along the rivers and in the Great Valley, as well as the most recent of the detrital fans of the arid eastern base of the range, are likewise to be ascribed to this period.

IV. THE ORIGIN OF YOSEMITE VALLEY.

1. General Statement.

Yosemite Valley is a widened portion of the canyon of the Merced River. The altitude of the floor is about 4,060 feet above sea-level near the Sentinel Hotel, and the surrounding cliffs rise on an average from 3,000 to 4,000 feet

above this floor; one point, Half Dome, reaching an elevation of 8,927 feet. While the valley is a portion of the canyon of the Merced River, it finds its natural continuation up-stream in the canyon of Tenaya Creek rather than in that of the Merced, which enters the valley at right angles to its general trend. This is brought out by a view (Pl. XXXI) which shows the east end of the valley and Tenaya Canyon beyond. Any one regarding the valley from a high point can hardly fail to be struck with the great size of Tenaya Canyon. The present Tenaya Creek appears to be entirely inadequate to the work it seems to have performed, even after allowing liberally for enlargement by the glacier that formerly occupied it.

Tenaya Creek finds its source in Lake Tenaya. The basin of this lake is separated by a low pass from that of Tuolumne Meadows. It has been suggested by Mr. Solomons, of the Sierra Club, that the upper part of Tuolumne River at one time flowed south through this pass into Tenaya Lake, thence finding its way into Tenaya Canyon, the great size of which may thus be accounted for. The plausibility of this is enhanced when we note that the present Tuolumne, for some miles west of Tuolumne Meadows, flows down in a series of cascades and appears to be cutting a new canyon. There is thus apparent evidence that the Tuolumne has captured the upper portion of the hypothetical former North Fork of the Merced River or the present Lyell Fork of the Tuolumne and its branches. An objection to this hypothesis, which is perhaps fatal, is found in the discovery, before noted, of a channel representing the Neocene Tuolumne River somewhat to the north of the present canyon of the Tuolumne. The pebbles of this Neocene river deposit consist largely of the slates and schists of the Mount Dana sedimentary area, showing that the Neocene Tuolumne River headed as it now does in the neighborhood of Tuolumne Meadows.[1] It would seem

[1] The slates and tuffs of the Mt. Dana belt are continued to the northwest, but there lie on the east slope of the Sierra Nevada, so that the slate and schist pebbles referred to could hardly have come from any other part of this belt, except as indicated from the head of the present Tuolumne drainage, that is, from Mt. Dana and vicinity.

very improbable that a river, having established a channel in Tertiary time, should be diverted in the early Pleistocene into another drainage, and at a somewhat later time revert to its original course.

To get a clear conception of the explanation of the formation of Yosemite Valley here presented, let us go back to the time when the drainage of the Merced was being initiated. The great granitic mass of the Sierra Nevada was, in all probability, at one time covered by other rocks, since all the evidence extant indicates that acid igneous rocks never become thoroughly crystalline except under pressure. In other words, granitic rocks have never formed at the surface of the earth. This original cover may be presumed to have been composed of pre-Cretaceous sediments and associated lavas, and remnants of it are to be recognized in the small areas of these rocks which form the summits of many of the high points. Let us suppose that erosion has gone far enough to have removed the larger part of this cover, exposing the underlying granitic rocks in nearly all the area under discussion.

Like all mountain ranges, the Sierra Nevada has been subjected to earth stresses. The original folding of the pre-Cretaceous sediments, the slaty structure, and the schistosity of the rocks are clearly all due to these stresses. In addition to the slaty and schistose structures, the older rocks of the range are intersected by systems of joints, which may also be due to compressive stresses. These joints comprise two vertical sets, two or more diagonal sets, and a horizontal set. As a matter of fact, it very seldom happens that all of these systems of joints are represented in the same rock mass. There is often a combination of one set of vertical joints with the horizontal joints, but in nearly all cases some one system is most strongly developed at a given locality. On Plate XXXII a set of vertical joints striking northeast and southwest is shown; and on Plate XXXIII a diagonal set may be seen.

When the streams of this early period began to form channels it is clear that the water would follow the jointed

or fissured zones, as lines of less resistance, and it is also clear that along such zones erosion would be more rapid than in the unjointed masses. At many points on the bare granite slopes of the Sierra surrounding the Yosemite, the course of small streams can be plainly seen to be determined by the joint planes. With the larger streams erosion has often gone so far as to obscure the relation of the joint planes to the course of the streams; yet if we plot the joints on the ridges enclosing the canyons, a parallelism to the general trend of the canyons may be frequently noted. Not only is the direction of the stream often determined by the direction of the joint planes, but the character of the enclosing walls, where these are solid rock, is also in a considerable measure determined by these planes. Thus, if the joints are vertical (See Plate XXXII), the walls will be vertical, and if diagonal, inclined surfaces will result, as for example, in the ravine of the Bridal Veil Creek above the falls, and at the Three Brothers. The joint planes here described should not be confused with the curved partings due to weathering, as seen on most granite domes.

In the course of long ages, the streams have cut deep canyons. Portions of the canyons where no strong joint planes intersect the rocks will then have the ordinary shape of river or glacial valleys, according as they are above or below the former limit of glacial ice; but where strong sets of vertical joints exist the river canyons will be bordered by cliffs. This was the case at Yosemite Valley; but before full evidence of this simple mode of the formation of the valley is presented it will be advantageous to take note of the views of previous observers.

2. *Views of Previous Observers.*

A valley so interesting and so much visited could hardly fail to have invited suggestions as to its origin. Professor J. D. Whitney, writing in 1865,[1] supposed the valley to have been the result of the dropping down of what is now its floor. At the same time he recognized that the valley

[1] Geology of California, Vol. I, 1865, p. 422.

had been occupied by a glacier. At a later date he denied[1] that there was any evidence of the former presence of glacial ice in the Yosemite, and stated more fully[2] his theory of its formation as follows:—

We conceive that during the process of upheaval of the Sierra, or, possibly at some time after that had taken place, there was at the Yosemite a subsidence of a limited area, marked by lines of "fault" or fissures crossing each other somewhat nearly at right angles. In other and more simple language, the bottom of the valley sank down to an unknown depth, owing to its support being withdrawn from underneath during some of those convulsive movements which must have attended the upheaval of so extensive and elevated a chain, no matter how slow we may imagine the process to have been. Subsidence over extensive areas of portions of the earth's crust is not at all a new idea in geology, and there is nothing in this peculiar application of it which need excite surprise. It is the great amount of vertical displacement for the small area implicated which makes this a peculiar case; but it would not be easy to give any good reason why such an exceptional result should not be brought about amid the complicated play of forces which the elevation of a great mountain chain must set in motion.

By the adoption of the subsidence theory for the formation of the Yosemite, we are able to get over one difficulty which appears insurmountable with any other. This is, the very small amount of debris[3] at the base of the cliffs, and even, at a few points, its entire absence.

This theory of Whitney's was later adopted by Kneeland,[4] Russell,[5] and Reyer[6] and very recently (1896) it was again recognized by J. W. Gregory, in a volume entitled the "Great Rift Valley". The valley referred to by Gregory lies in British East Africa, west of Mount Killimanjaro. By rift valley is here meant a depression formed by the dropping down of faulted blocks, and not a yawning apart of the earth's crust along a fracture. Such a depression would be called a "*graben*" by Suess. As previously stated, Mr. W. Lindgren[7] regards the basin occupied by Lake Tahoe as formed in this way. The Yosemite is referred to by Gregory as being a rift valley in this sense.

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[1] The Yosemite Guide Book, 1874, p. 117.

[2] Ibid., pages 119-120.

[3] The largest talus slopes known to the writer in the Sierra Nevada are those of the north side of Yosemite Valley, west of El Capitan, and of the south side east of Cathedral Rocks and west of Bridal Veil Falls, and the lack of talus at other points is no more striking than in most glacial canyons.

[4] Kneeland, Proc. Bost. Soc. Nat. Hist., Vol. XV, 1873, pp. 36-47.

[5] Russell, Eighth Annual Report, U. S. Geol. Surv., Part I, 1889, p. 351.

[6] Reyer, Neues Jahrbuch, 1886, Beilage Band IV, Heft 2, pp. 291-326.

[7] Jour. Geol., Vol. IV, 1896, p. 895.

Professor Joseph Le Conte in 1872[1] thought the valley had been filled to its brim by a glacier and cut out by glacial action. The remarkable verticality of the walls was regarded as the result of the perpendicular cleavage of the granite. The domes were regarded as due to a concentric structure in the granite, combined with ice erosion. Le Conte in a late paper[2] is now inclined to adopt the fault theory of the origin of Yosemite, but he recognizes that the exceptional verticality of the walls of the Yosemite is especially due to the vertical "cleavage" (jointing) of the granites of the region, and states that the walls are now slowly receding by vertical scaling and thus retain their perpendicularity. However, it appears to the writer that the vertical walls of the Yosemite, together with its great depth, form the strong points in favor of the fault theory, and that if these phenomena can be otherwise accounted for, the fault theory is no longer necessary.

In the same paper Professor Le Conte considers that transverse river canyons of the ordinary type have formed by erosion in the ordinary manner "along incipient fissures," likewise transverse to the general trend of the range. Professor Le Conte says:—

> In the elevation of a mountain range there is of necessity a *stretch* along the axis proportioned to the amount of elevation, which must *tend* to produce transverse fractures. It may produce real fissures or only what I call *incipient fissures*, or a loosening and jointing along planes transverse to the axis. In the Sierra it was probably *mostly* incipient fissures, sufficient to locate the position and facilitate the excavation of the valleys.

It might here be noted that joints formed as described above would be tensile joints, while Becker and others regard most of the joints referred to in this paper as compression joints.

John Muir, writing in 1873,[3] supposed the valley, and in fact the topography of the entire range from base to summit, to have been the work of glacial ice. He noted

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[1] On Some Ancient Glaciers of the Sierras. Proc. Cal. Acad. Sci., Vol. IV, 1873, p. 261.

[2] The Origin of Transverse Mountain Valleys and Some Glacial Phenomena in Those of the Sierra Nevada. University Chronicle, Vol. I, No. 6, December, 1898, Berkeley, California.

[3] Proc. Am. Assoc. Adv. Sci., Vol. XXIII, Part II, 1875, pp. 49–64.

that the granite of the Sierra was divided into polyhedrons by sets of partings; two vertical horizontal and others diagonal to these. Although he does not clearly state it, he evidently regards the vertical walls as due to erosion along vertical partings, the benches as due to erosion along horizontal partings, and the inclined surfaces in some cases due to erosion along diagonal partings. Muir writes:—

The Yosemite Half Dome, the noblest rock of the Sierra, perhaps, also furnishes admirable illustrations of all kinds of cleavage and of their effects upon form. Its upper part, for about one thousand eight hundred feet, is almost absolutely vertical, while the lower three thousand feet is inclined at an angle with the horizon of about 37°. On the notch a section of the dome may be seen, showing that it is there made up of immense slabs set on edge, evidently produced by cleavage planes which, cutting the dome perpendicularly, have determined the plane of its face. Along the base of the vertical portion the stumps of slabs are exhibited, which have been successively split off the face while the rock was in process of formation by the Lyell, Tenaya, and Hoffmann glaciers.

Moreover Muir noted a mode of erosion by ice which has since been brought into greater prominence by Mr. Willard Johnson. He writes:—

Again, we find this mighty ice-tool *undermining* from beneath what it could not grind away from above, eroding backwards into the basis of peaks and pinnacles.

This presumably refers to the formation of glacial cirques, which will be referred to further on.

Mr. Gilbert[1] thought that "the great glaciers of the Sierra Nevada occupied an antecedent system of valleys, shown by their form to be the product of stream erosion. The period of ice was, therefore, preceded by a period when there was no ice or little ice, and this antecedent period[2] was of relatively great duration."

In an important paper,[3] Dr. G. F. Becker describes in detail the sets of joints or fissures to which Muir refers. As my own results are a confirmation of those of Becker, as to the distribution of these joints and their relation to the formation of canyons, I will quote from him at some length. I have not myself seen, however, much evidence of the

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[1] Lake Bonneville, Monograph I, U. S. Geol. Surv. 1890, p. 269.
[2] This would be the Sierran Period. H. W. T.
[3] Bull. Geol. Soc. Amer., Vol. II, 1891, pp. 67–69.

faulting[1] described by Becker as common along these fissures or joint planes, although there are sheared zones in the granite areas where the surfaces of movement show slickensides, and unquestionable faults accompanied by crushing and shearing are occasionally found. Dr. Becker writes:—

> The granite and other granular rocks are intersected by fissures at short intervals. Sometimes these appear to be without any regularity; but much more often they are manifestly grouped in systems. A few square miles will be particularly characterized by horizontal fissures, and here the granite mountains will appear terraced. In such cases the vertical or diagonal fissures are always present, but are less prominent than the horizontal partings. In other areas the granite will be intersected by diagonal fissures usually dipping at about 45° and striking between northwest and north. These dip in both directions and divide the mass into horizontal columns. Much more frequent than any other fissure systems are vertical partings, and these are remarkably uniform in strike, almost always running either nearly north-northwest or at right angles to this direction. Though the fissures in the granite never gape and are usually only cracks, they are not mere partings or joints[2] but true fault planes. * * * In innumerable cases they show excellent slickensides and very often the amount of dislocation can be demonstrated. The faulting has been attended by intense compression, so that at some points the rock for an inch or two from the principal plane of motion has been sheared to a mass resembling slate. This is comparatively rare, but it is often manifest that, for some distance from a pronounced fissure, lines of weakness have been developed in the rocks at intervals of a quarter of an inch, or thereabouts. These lines grow less distinct as the distance from the fissure increases, and disappear a foot or two from the fissure.

Effect of Irregular Distribution.—A few notes may next be made with reference to the effects of the fissure systems on the course of events in the part of the Sierra here discussed. As has been mentioned, the distribution of fissures is not uniform. In many places one system or the other is highly and almost exclusively developed. Sometimes the rock is divided into very regular prisms of indefinite length, and again these are cut by horizontal partings into rectangular blocks. Finally, there are areas in which the mass consists of polyhedral fragments.

The rate at which decomposition and erosion will take place clearly depends upon the frequency of the fissures of a system and the number of fissure systems developed in a given locality, for both erosion and disintegration vary with the amount of surface exposed per unit volume. Thus, where the granite is shattered into fragments of small size, disintegration will

[1] I refer here particularly to the systematic faulting described by Becker, in which the upthrow is always on the east side, which, if true, would cause in the total a marked elevation of the crest of the range.

[2] In a more recent paper, Bull. Geol. Soc. Amer., Vol. IV, 1893, pp. 13–90, Dr. Becker (p. 73) comes to the conclusion that jointing and faulting are concomitant.

be rapid and heavy showers will move the blocks, while masses of large size will remain unmoved and decompose slowly. The patches and zones where the shattering has been relatively thorough will thus be carved into hollows and ravines, while the more solid parts of the mass will remain as hills or mountains.

Formation of Cañons.—The influence of these relations is very sensible in the Sierra and every step of the process can be traced on a large or small scale. The shattered zones commonly follow the direction of one of the main fissure systems, and so do many of the cañons, large and small; but the zones sometimes jump across from one set of fissures to another parallel set belonging to the same system, and so, too, do the cañons. Such zones also sometimes end abruptly—a fact due, no doubt, to variations in the composition of the rock. The cañons do the same.

Ice seems to have played a considerable part in clearing the cañons of fragments and in excavating shattered and decomposed patches, so that in a sense one must ascribe a large erosive effect to the glaciers; but the ice seems, nevertheless, to have been incapable of cutting into solid masses to any extent, or even into much fissured rock where little decomposition had preceded and where the blocks were tightly wedged together. * * *

In the area here dealt with there are gorges resembling the Yosemite Valley in the most striking manner, though on a small scale, but so exposed as to show that their existence is due simply to local intensification of the shattering process. In one especially striking instance in the district known as Border Ruffian the gorge is on the east-northeast vertical fissure system, but the fissures are slightly inclined to the southward through some irregularity in resistance. Faulting has consequently produced irregular cross-fractures of the mass and reduced it to more than ordinarily small fragments. Weathering, water and ice have then done their perfect work and cut the mass down to the lowest possible level, leaving, however, the rocky floor exposed. * * * If the fault system studied in this paper extends to the Yosemite, as the fissure system certainly does, the valley cannot be due to a local subsidence. On the other hand, I can see no objection to the hypothesis that the shattered zone of rock was disintegrated and eroded in pre-glacial times, the process being completed by a glacier which left a small moraine near the entrance and thus converted the valley into a lake.

Whitney,[1] Gilbert,[2] Russell,[3] and Becker[4] agree in supposing the present drainage system of the Sierra to have been far advanced before the time when the ice occupied the canyons, while Muir believes that ice carved out all the canyons of the Sierra Nevada. It is, therefore, to the point to examine into the question of the power of ice to erode.

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[1] Whitney, Geol. Cal., Vol. I, 1865, p. 421, and elsewhere.
[2] Gilbert, Mon. I, U. S. Geol. Surv. 1890, p. 269.
[3] Russell, Eighth Annual Report, U. S. Geol. Surv., Part I, 1889, p. 349.
[4] Becker, Bull. Geol. Soc. Amer., Vol. II, 1891, pp. 67–69.

3. *Erosive Power of Ice.*

Prof. Albert Heim,[1] a thorough student of glacial geology, writes:—

> Advancing glaciers often leave loose detritus undisturbed [where the glacial valley widens]. Under other circumstances, particularly in contracted valleys where there are obstructions, the advancing glacier plows up the ground down to solid rock. * * * It is only loose masses standing very much in the way which were pushed along by the glacier.

Whitney[2] and Irving[3] likewise ascribed very little erosive power to glacial ice.

Geikie,[4] Bell,[5] and others apparently are of the opinion that glaciers considerably modify the shape of the masses of rock over which they pass. Indeed, that they do so is obvious to anyone who observes the rounded forms of the roches moutonnées, characteristic of the beds of glaciers. The scouring and polishing work of the ice is admitted by all observers, but all this is a very different matter from the gouging out of canyons by ice, as supposed by Muir and others. Indeed Heim and Becker regard the ice sheet as causing the relative suspension of valley formation. Becker considers that the former ice-cap of the higher part of the Sierra Nevada in a large measure protected from erosion the underlying rocks. On the other hand, it is clear that the silt-laden waters formed by the melting of a glacier, chiefly near its terminus, would form an active erosive agent, and this stream would not begin at the edge of the ice-mass, but further up the canyon under the glacier.

As stated by Geikie,[6] an approximate measure of erosion by glaciation may be obtained from an estimate of the amount of sediment in the glacial streams and from the size of the moraines. The average quantity of sediment discharged from the melting end of a glacier during a year having been estimated, it would be easy to determine its

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[1] Handbuch der Gletscherkunde, 1885. The quotation is taken from Becker's paper on "The Structure of the Sierra Nevada," p. 65.

[2] Climatic Changes, 1882, p. 8.

[3] Quart. Journ. Geol. Soc. London, 1883, pp. 62–71.

[4] Text-Book of Geology, 1893, pp. 429-431.

[5] Bull. Geol. Soc. Amer., Vol. I, pp. 287-310.

[6] Text-Book of Geology, 1893, p. 432.

equivalent in the precise fraction of a foot of rock annually removed from the area drained by the glacier. The amount of material falling from the cliff and deposited as moraines may evidently be estimated directly from the moraines themselves. Of course this method applies only to living glaciers. Helland[1] estimated that there is annually carried off by the Justadel glacier in Norway, covering an area of 830 square kilometers, 180,000,000 kilograms of rock, at specific gravity 2.6, or an average of 217,000 kilograms per square kilometer. As pointed out by Geikie, this includes the sediment washed into the glacial river from surrounding slopes by running water, and in summer the amount from this source must be considerable. At the same rate, the Yosemite glacier, with a superficial extent during the epoch of maximum glaciation of about 300 square kilometers, must have carried off annually during that epoch 65,100,000 kilograms of rock. These are very large amounts, and if reliable would indicate a greater degrading power than is ordinarily accredited to glaciers.

Russell[2] attempted to determine the amount of material removed by ice action from Lundy Canyon, on the east slope of the Sierra Nevada, by the size of the moraines and the size of the delta where Lundy Creek enters Mono Lake. This delta is regarded by Russell as being largely made up of glacial sediment. The conclusion was that the amount removed in this manner from the canyon was greatly less than its entire cubic space, indicating that the canyon had been largely formed by stream erosion before being occupied by the ice. However, as Russell remarks, the amount of fine sediment carried farther into the lake and deposited cannot be estimated. The conclusion of Russell as to the inadequacy of ice erosion to account for the canyons draining into Mono Lake applies with equal cogency to the greater canyons on the west slope. The amount of morainal material in the Merced drainage area is insignificant in comparison with the size of the canyons of the Merced and its

[1] A. Helland, Geol. Fören. Stockholm Förhandl., 1874, Band II, pp. 212–213.
[2] Quaternary History of Mono Valley, p. 349.

tributaries. As in the Mono Lake basin, however, the amount of silt from the glaciers carried off into the San Joaquin Valley cannot be estimated.

4. *Rock Basins.*

Among the proofs of great abrasion by ice on rock surfaces, the existence of basins apparently scooped out of solid rock is perhaps the most striking. In 1859, Sir. A. C. Ramsay first ascribed the origin of these basins to the action of land ice. His views were not at once accepted, and, in fact, so recently as 1882, Reverend A. Irving[1] concludes, on mechanical grounds, that the actual excavation of lake basins by glacial ice is inadmissible. Such rock basins are abundant in all mountainous glaciated regions. They certainly do not represent original depressions of the surface, for the original surface has long since disappeared, and are plainly not due to subsequent orographic movements. At least this is the case with all those referred to in this paper. The conclusion is therefore drawn that their origin is in some manner due to glacial ice, or perhaps in part to the ice streams that at some points dash through crevasses onto the underlying rocks, although such ice streams probably, in most cases, merely erode potholes.

Glacial markings may often be traced down below the water at the upper end of the lake and found emerging at the lower end with the same steady direction as on the surrounding rocks. In the glaciated regions of the Sierra Nevada, rock basins are very abundant. These have already been described by Russell and others. The rock in which they have been found is ordinarily granite. Many of these rock basins are at the base of steep slopes, and it is possible in such cases that the great downward pressure of the ice excavated such basins, especially where the rock was much jointed. The location of other rock basins, however,

[1] "On the Mechanics of Glaciers, with Special Reference to Their Supposed Power of Excavation." Quart. Jour. Geol. Soc. London, Vol. XXXIX, 1883, p. 62.

although always where the ice mass appears to have been very thick at one time, is such as not to suggest the probability of there having been sufficient weight of ice to scoop out a basin in hard rock. Such is the basin occupied by Lake Washburn (See Plate XXXIV), which is an expansion of Merced River several miles up-stream from Yosemite Valley. Even here, however, there is a steep bare granite slope immediately west of the lake, but none up-stream, from which direction the ice chiefly came. It is more than likely that in many such cases the basin was originally produced by unequal disintegration of the granite in preglacial time, this decomposed material being subsequently excavated by the ice.

These rock basins are sometimes more than a mile in length. The blue color of the water of the lakes that occupy them suggests some depth. Two of them were sounded: the larger, Lake Tenaya, with a length of about one mile, was found to have a maximum depth of about ninety feet; the smaller, Johnson Lake, with a maximum diameter of about one-fourth of a mile, showed a maximum depth of about forty-five feet. As no rock bottom was found in either of the basins, the depth to the solid rock must be in both cases something more than is given above. In the illustration, the rock barrier forming the lower side of the basin of Lake Washburn can be plainly seen, together with the outlet of the lake.

Helland[1] describes small rock basins lying in glacial cirques, which may be explained by the sapping theory of Johnson, referred to under "Glacial cirques." Helland writes:—

> These lakes are not formed by moraines damming the water, but are truly rock basins; and it does not seem likely that they were mainly scooped out like the great lakes, along the sides of which we often see groovings and roches moutonnées; for in the little lakes one often sees sharp-edged blocks covering the bottom. When the glaciers of the cirques filled these small lakes so as to leave but little water, it seems probable that the water thus left would freeze in winter, so that the whole tarn would thus be frozen to the bottom and the rocks in that way broken loose.

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[1] Quart. Jour. Geol. Soc. London, Vol. XXXIII, 1877, p. 165.

Tiny rock basins sometimes form on the surface of granite and other rocks, and some such are described by Geikie as occurring in the southwest of England. The Kettles and Pans figured by him in his text-book are of this nature. Similar rock basins are abundant in the Sierra Nevada. After rains they commonly contain water. They are often more or less rounded in shape, and are from a few inches to a few feet or more in diameter. It is evident in this case that these rock basins are purely the result of weathering, the material being blown out by high winds. Plate XXXIX represents such a basin, the bottom of which was covered with about two inches of coarse granitic sand. Its width is about three feet and its depth six inches. This particular basin appears to have originated from the disintegration of a dioritic nodule enclosed in granite, the cavity thus formed being subsequently enlarged. Dioritic nodules in this granite can be seen at many points in various stages of removal, they being here softer than the enclosing granite.

The following statement by Professor Chamberlin, of the University of Chicago, was kindly communicated by letter:—

While I think the action of ice in scooping out rock basins, in the production of cirques, and in the refashioning of valleys, has notable limitations in its extent, I believe it to be, nevertheless, a phenomenon of some importance. The most satisfactory evidence which I have seen personally is in Newfoundland, where on the summits of plateaus, basins have been excavated in sandstone in such a fashion as to completely exclude the agency of ordinary stream action, and also apparently that of solution, since the rock was essentially insoluble. Disintegration may have prepared the way for excavation, but it had obviously not reached the full extent of the excavated basin, since the bottom and sides were ragged with the fractured faces of sound rock. These basins were not simply rasped out. The rock was obviously torn away from its place in blocks. The basins are generally small, being a few rods in diameter and a few feet in depth, but they seemed to be unquestionable examples of mechanical excavation.

In Greenland I saw much evidence of mechanical disruption, but I do not recall any specific cases of basin formation, yet this is not strange, as the topography of the region I studied was, on the whole, unfavorable to that class of action.

I think that in most cases of this kind there must be something in the antecedent topography to determine this particular kind of action. I suppose that diffierential action might form a basin in the midst of a plain, but I should suppose such action would be very rare. So far as my observation goes the

general effect of glaciation is to reduce inequalities, especially when the whole surface is covered by an ice sheet. When the ice is forced by topography to take the form of tongues on the border of an ice-sheet, or when the glacier is but a tongue, owing to its formation in a valley, the action may intensify the topographic differences.

5. Glacial Cirques.

At the head of glaciated canyons there are usually amphitheaters with steep walls. These have been called cirques.

Where the rock is intersected by horizontal and vertical joints or other structural lines, the deepest cirques are formed, with nearly vertical walls and nearly horizontal floors. Where the rock is relatively unjointed, as on the slope east of Royal Arch Lake, which is an incipient cirque bordered by local moraines, the floor of the cirque slopes upward and the walls are seldom high. Such slopes with massive rock are usually undergoing exfoliation. Incipient cirques like those at Royal Arch Lake are very common and were mostly formed late in the glacial history of the range, by residual or "hanging" glaciers. A much better example of an incipient cirque than that at Royal Arch Lake may be seen on the north slope of a rounded granitic hill (altitude 9,202 feet), which lies seven miles a little west of north from the summit of El Capitan. This slope is evidently undergoing exfoliation, and the ice has eaten out a shallow amphitheater with steep walls; but the general inclination of the sloping floor of the amphitheater is evidently determined chiefly by the exfoliation partings.

The cirques of the Sierra Nevada are referred to at some length by Russell in his monographic paper on Mono Valley.[1] As Professor Russell shows, a number of geologists regard the cirque as a product of ice erosion. According to Helland,[2] Lieutenant Lorange, a Norwegian Engineer, "formed the opinion that the cirques and some fjord-valleys of Norway were formed by glaciers. Under the glaciers in cirques, where a space intervened between the bed of the cirque and the ice, he saw a great many stones,

[1] Quarternary History of Mono Valley, California. Eighth Annual Report, U. S. Geol. Surv., Part I, 1889, pp. 352–355.

[2] Quart. Journ. Geol. Soc. London, Vol. XXXIII, 1877, pp. 142–176.

some of which, sticking fast in the glacier, were quite lifted up from the bed of the cirque, while others were touching or resting on it. He thinks it probable that as the temperature around the glaciers constantly varies about the freezing point, the incessant freezing and thawing of the water in the cracks in the rock may split it, and the glaciers may do the work of transportation for the fragments thus broken loose. On examining the interior of an empty cirque, we observe that a bursting, not a scooping-out of the rocks has taken place."

Dr. Becker[1] describes a mode of erosion, suggested by observations in Alaska, which embodies practically the same idea as that just described. He writes:—

> In considering the glaciers at various points it occurred to me that disintegration must be extremely rapid along the edge of the ice, for the temperature of the ice being zero centigrade, the number of days in the year must be great upon which the adjoining rock is chilled below the freezing point at night and raised above the melting point during the day, and such alternations form a most efficacious means of breaking up solid rock. * * * * * It appears to me that all along the edge of a glacier and along its névé field as well, frosts must be more frequent than, *ceteris paribus*, at a distance from them, and that disintegration must be correspondingly rapid. The U-shape assumed by glacial gorges and the cirques at the névé basins may be in part explicable in this way.

Johnson's Theory.—Mr. Willard Johnson, in a paper read before the Geological Society of Washington, had previously presented nearly the same theory for the formation of cirques and steps in glaciated canyons, although this was not known to Dr. Becker at the time of his writing the above; but Mr. Johnson considers that this mode of erosion produces results greater in amount than should perhaps be ascribed to it. The following is an outline of the main features of the theory, which he kindly wrote out and placed at my disposal. The steps of the cyclopean stairway found in some of the glaciated canyons are regarded as the work of ice, and the formation of these steps is the first point described.

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[1] Reconnaissance of the Gold Fields of Southern Alaska. Eighteenth Annual Report U. S. Geol. Surv., Part III, 1898, p. 60.

The glacier ordinarily affords protection against the temperature changes which fracture the exposed rock of the bordering mountain slopes above its surface, yet the glacier keeps at a low temperature the rock surface it covers. Therefore, if the glacier be broken across, so that communication may be had with its bed by the outer air, the line of rock-bed thus exposed to exceptional contrasts of temperature may be disrupted in consequence. The transverse crevasse, carried forward at the top, will presumably have its foot at the base of the bluff. In summer only will this crevasse as a rule remain open. And in summer there may be set up, at the base of the buried cliff, through the communicating air of the open crevasse, alternations across the freezing point between night and day. The result must in such case be sapping of the cliff. Alternations of temperature on the bare slopes without are not diurnal but annual. This subglacial process of cliff weathering, with concentration of weathering at its foot, will be relatively rapid. The tendency of course will be downward, as well as horizontally backward. But downward fracturing will be defeated by the difficulty of removal of products. Hence the floor will be maintained approximately flat, following with its extension in the trail of the receding cliff. It will not, however, be absolutely flat; furthermore, outward a little from the lee of the cliff, abrasion will resume its work of smoothing and polishing, interrupted at the upper lip of the cliff, and these irregularities of the approximately level floor, revealed by stream ponding after glacial withdrawal, will constitute the shallow rock basins so much discussed.

Given the process of undercutting at the cliff base, the height attained by the cliff, in its recession into a rapidly rising grade, will not affect the efficiency of the process. No more work of sapping is required to undermine a high than a low cliff, given complete removal of the débris. The height, however, may be limited by the depth to which open crevassing will penetrate. In fact, there seems to be such a limit. Yet terrace steps of several hundred feet, nearly sheer fall, occur. Above the limiting height, a second step, of more vigorous recession, will be initiated. Terracing thus results. As it is immaterial, in the progress of undercutting and undermining, what height the cliff may eventually come to have, so it is immaterial how high the side walls may become in this low-grade eating backward into the high-grade slope. Hence, under favorable conditions—which must be of rare occurrence—a Yosemite and a Hetch Hetchy Valley is a possibility.

It is in the summit region of a glaciated range that work of this character becomes most marked. Here, at the head of the individual ice-stream, the cirque, or glacial amphitheater, unlike the head region of the stream of water, nourishes the glacier full-born at once and exhibiting its maximum of destructive efficiency. The amphitheater wall is but the last in the series of cliffs, and though the stream does not become broken to its foot by overriding it, it nevertheless has its crevasse—the 'bergschrund'—following the semicircle a little out upon the body of the ice; and the encircling amphitheater wall is also a cliff of recession. It is exceptionally high, not because the glacier continues on a level for a larger space at its head here, but because, with the glacier following persistently the same habit of horizontal burrowing, it works into steeper slopes. Hence the amphitheater is the most notable of glacial forms. It indicates the heaviest degradation. But since its wall is produced

by undermining, and is, therefore, a wall of recession, results of profound importance are to be looked for as an outcome of head-stream erosion. Obviously, for example, recession here may carry the amphitheater rim across the divides, and thus cut through the divide crest.

In another portion of the statement, Mr. Johnson writes, in speaking of the steps or terraces in the canyons:—

Jointing may lend itself incidently to their development, or it may confuse it. Commonly its influence would be unimportant, but the most clearly typical development is to be found where for considerable stretches the rocks are massive and have no joints whatsoever.

In all places where the steps above referred to are to be found, my own observation is that there exists a horizontal joint structure, although the joints may be hundreds of feet apart, and consequently few joints, or sometimes no joints at all, will appear on the escarpment of any given step. For example, at Nevada and Vernal falls, where the step structure is finely developed, the horizontal joints are very evident, but there are none on the escarpment of the Vernal Falls.

From the foregoing, it will appear that glaciers may: First, modify the basins in which they are born, so as to form steep walled cirques;

Second, modify the shape of the canyon down which they flow;

Third, excavate under advantageous circumstances basins in the underlying rocks.

That they form the gigantic steps before described as occurring in glaciated canyons is improbable, although they enlarge them. Such steps occur along streams below the limit of glaciation, where the rocks are intersected by horizontal joints; and as stated above, in all those cases which have come under my observation in the glaciated region of the Sierra, horizontal joints are found in the granite wherever the steps have formed. The theory that great canyons or even considerable ravines are formed by the gouging action of ice does not seem supported by the evidence. The conclusion may thence be drawn that the canyons of the Sierra Nevada, like most other canyons the world over, were formed in the main by river erosion.

6. *Cause of the Glacial Period.*

Without endeavoring to elucidate the various theories that have been advanced to account for the Glacial Period, it may still be in place to call attention to certain general facts concerning it.

The immediate cause of the Glacial Period in the Sierra Nevada, as elsewhere, is undoubtedly to be ascribed to heavy precipitation combined with a sufficient degree of cold to cause the water to fall as snow. These conditions could be brought about by a greater elevation of the land or by a general change of climate. In the Sierra Nevada there is excellent evidence that the range stood higher in Pleistocene than in Middle Tertiary time, but there is no good evidence, so far as I can see, that the range is not approximately as high now as during the time when the ice last occupied the canyons; for while the general altitude of the range has been decreased by erosion, it may likewise have undergone some elevation, as seems to be suggested by late displacements along the old fault zones. Moreover, the most vigorous erosion in Pleistocene time was certainly that of the Sierran Period, which, as we have seen, in the main preceded the Glacial Period.

A general review of the glacial history of the northern hemisphere appears to suggest that glaciation was a general phenomenon and occurred at the same time at all points. If this be true, the cause of glaciation was evidently cosmic and cannot be ascribed to elevation alone, as it seems improbable that all of the northern hemisphere experienced a general elevation at the same time.

The yearly precipitation at Summit Station on the Central Pacific Railroad (altitude 6,750 feet) varies from twenty-three to eighty-eight inches,[1] and if it is as great as this along the crest of the range in general, a slight average decrease of temperature would cause the pigmy glaciers of the Sierra Nevada of to-day to again advance. In the winter of 1889 (?)

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[1] Physical data of Statistics of California, State Engineering Department, Sacramento, 1889.

there was an unusually heavy snowfall in the Sierra Nevada and the banks of snow that remained in the range during the entire summer following were much larger than usual.

7. *Evidence of Two Periods of Glaciation.*

In Europe there are evidences of two periods of maximum glaciation, an interglacial period intervening, during which the animals and plants that had been driven south by the increasing cold of the advancing ice returned to more northern latitudes. The remains of these animals and plants are found in the deposits of this interglacial period. There appears also to be evidence that at this time a subsidence occurred and that much of Great Britain was submerged.

In the eastern United States likewise, Chamberlin and others recognize what they regard as good evidence that such an interglacial epoch[1] existed in North America, probably contemporaneous with the European period. In the eastern United States and in Europe the glaciation of the second epoch was not so extensive as that of the first, and thus Gilbert's conclusion that the maximum of glaciation in the Cordilleran region occurred in the second glacial epoch of that region does not bring the phenomena of glaciation of the Cordilleras into complete harmony with the phenomena observed elsewhere. The imperfect evidence hereafter presented, suggesting that there were two glacial epochs in the Sierra Nevada, implies that during the first epoch the ice was more extensive than during the second epoch, and this plainly harmonizes with the results obtained in the northern United States and in Europe.

During early Pleistocene time the Great Basin contained a large number of lakes. Remnants of these still exist, but the surface now covered by the lake waters is trifling compared with the surface so covered in early Pleistocene time. There is here indisputable evidence that the climate

[1] The interglacial epoch here referred to is the first or main epoch. More than one interglacial epoch is recognized by some geologists but there appears to be a marked difference of opinion on this point.

of the western Cordilleran region was much more moist during a former period than now. So far as can be judged from the equal perfection of preservation of the lake deposits and from the similarity of the fossils contained in them, they existed at the same time and in fact resulted from climatic conditions which could not have been local. One of these conditions which favored the formation of lakes would be greater precipitation of rain and snow. This would likewise favor the formation of glaciers in the cooler air of the mountains. Direct evidence, indeed, exists of the coexistence of the glaciers and the early Pleistocene lakes, as will be noted later.

A large part of western Utah was formerly covered by a body of water known as Lake Bonneville, the old shores of which are recorded by the terraces which surround Great Salt Lake Valley. These terraces are plainly visible from the car window on the Central Pacific Railroad. Gilbert, in his elaborate study of Lake Bonneville[1], obtained evidence of two periods of high-water, with an intervening low-water epoch. During the first period the Yellow Clay was deposited; in the low-water or inter-Bonneville epoch alluvial deposits were formed; then came a second period when the water rose higher than in the first high-water epoch. During this second period the White Marl was deposited, and this rests unconformably upon the Yellow Clay of the first high-water epoch.

In western Nevada another Pleistocene lake, known as Lake Lahontan, was studied by Russell[2], who found three sets of lake deposits separated by unconformities: (1) lower lacustral clays representing the first high-water epoch; (2) medial gravels indicating shallow water; (3) upper lacustral clays representing the second high-water epoch. The history of these two lakes as read by Gilbert and Russell is thus the same. In his investigation[3] of Mono Lake

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[1] Monograph I, U. S. Geol. Surv., 1890.
[2] Monograph XI, U. S. Geol. Surv., 1885.
[3] Eighth Annual Report U. S. Geol. Surv., Part I, p. 305.

basin, Russell was unable to get any positive evidence of two high-water periods, but as Gilbert remarks,[1] this may easily be due to imperfection of exposure.

The direct evidence of the coexistence of glaciers and these Pleistocene lakes consists in the association of moraines with the lake deposits. In the case of the Lahontan basin no glaciers extended down to the lake level, but at Lake Bonneville, Emmons and Gilbert describe moraines which lie within the area of the lake beds. These moraines were deposited by glaciers from the Wasatch Mountains. From the field evidence Gilbert concludes that these moraines were formed during the second high-water epoch, but before the water was at its highest stage, since the moraines do not show any trace of the Bonneville or highest shore-line, as they probably would if they had been formed previous to this highest stage of the water.

At Mono Lake[2] there are several moraines which extend into the area formerly covered by the lake waters in earlier Pleistocene time. On these moraines, both the older and the newer according to Gilbert, the waves cut a shore-line more or less distinct,[3] showing that they had been deposited before or during a high-water stage of the lake.

Fossil shells from the Lake Bonneville beds of the second high-water epoch were compared by Call[4] of the Smithsonian Institution with recent shells of the same species from Utah Lake, a fresh-water residual of Bonneville, and were found to be smaller. Call also found that the shells of fresh-water molluscs were of smaller size in cold than in warm waters, hence the conclusion that the water of Lake Bonneville at the second high-water stage was colder than the water in the same region to-day. Salinity also has a retarding influence on the growth of the shells of fresh-water molluscs, but as Bonneville overflowed in glacial times, it is fair to assume that the water was fresh.

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[1] Monograph I., U. S. Geol. Surv., 1890, p. 306.

[2] Russell, Eighth Annual Report, U. S. Geol. Surv., Part I, 1889, p. 369. Gilbert, Monograph I, p. 311.

[3] This was also noted by Clarence King. See Whitney, Climatic Changes, p. 51.

[4] Bulletin U. S. Geol. Surv., No. 11, 1884.

Gilbert summarizes his conclusions as follows:—

The evidence from the moraines is thus shown to be consistent with that from the molluscan fauna, and they generally confirm the presumption derived from the recency and exceptional nature of the lakes and glaciers, that the two phenomena were co-ordinate and synchronous results of the same climatic changes.

Since there were two periods of lake expansion, Gilbert likewise concludes:—

That the Glacial Period of the Sierra Nevada, the Wasatch, and other mountains of the Western United States was divided into two epochs separated by an interglacial epoch, but this has not been independently shown.

Since the Wasatch glaciers extended into Lake Bonneville apparently only during the second high-water epoch, the conclusion is drawn that the accumulation of ice was greater in the second than in the first period.

The conditions that brought about the glaciation of part of two hemispheres could hardly have ended abruptly at the western and southern limit of the great ice sheet of the great continental glacier; hence the two hypothetical epochs of glaciation of the western Cordilleran region may be correlated with the two epochs of the great continental glacier of the northern United States and perhaps with the same epochs in Europe.

Evidence of Two Ice Periods in the Sierra Nevada.— Thus far, however, there has been no positive evidence obtained in the range itself that will warrant us in dividing the Glacial Period of the Sierra Nevada into two epochs. Certain facts, however, may be said to point in this direction.

The comparatively gentle surface of late Tertiary time began to be dissected by streams in the early Pleistocene. Let us suppose that the first epoch of glaciation of the Cordilleran region corresponded in time with the first epoch elsewhere, and hence began before the close of the Sierran Period or before the canyons had attained their present great depth. Much of the higher portion of the Sierra Nevada may then have been covered by ice. An extended

view of the range about Yosemite Valley below the altitude of 10,000 feet presents the aspect of a great plateau, on which are numerous dome-shaped eminences. About this gigantic roches moutonnées-like[1] surface rise rugged peaks over which glacial ice has never moved. The surface of this approximate plateau is trenched by glaciated canyons. Along the sides of these there are sometimes benches which could be regarded as remnants of former shallower canyons. In other words, there are traces of canyons within canyons. The benches just referred to may be regarded as portions of the shallower canyons of the first glacial epoch. During the time when the ice covered the surface, these river valleys, in part inherited from the Tertiary, would not be greatly deepened, but rather would be protected from erosion by the ice sheet. The narrower and deeper canyons of the present day may be supposed to have been cut in an interglacial epoch; then followed the second glacial epoch, when the ice protruded in tongues down the new-cut canyons for long distances but never extended as far from the crest of the range as during the first epoch. The ice of this second period greatly modified the new-cut canyons of the interglacial epoch, and gave them, within the glaciated area, substantially their present form.

During the field season of 1897 a trip was made through the Yosemite National Park in company with Professor C. R. Van Hise. Mr. Theodore Solomons, a thorough mountaineer and a member of the Sierra Club, acted as guide and took the party through some of the most rugged and interesting portions of the region. On his return, Professor Van Hise wrote out some rough notes of his interpretation of the topography of the higher Sierra Nevada, and kindly placed these at my disposal. He was much impressed with the important part that ice seems to have played in moulding the topographic forms, and regarded the benches previously referred to as portions of earlier,

[1] Although the ice has moved over these domes, their shape in the main is due to exfoliation and not to ice erosion.

shallower river valleys, and found in the topography what he considered good evidence that there was more than one period of the ice extension.

Russell[1] has compared the steps formed in some of the glaciated canyons to a cyclopean stairway. These steps have formed by erosion along horizontal joint planes, but Professor Van Hise does not regard them as the result of river erosion, giving as an example the fine steps at the Nevada and Vernal falls, and Russell and Johnson think that the steps are allied to cirques in origin. However, as heretofore stated, I have seen exactly such steps, on a smaller scale, formed in stream beds with a high grade, where the rocks are intersected by horizontal joints, far below the limit of glaciation; for example, in some of the ravines on the west slope of the Chowchilla Mountains, where they are cut out of Carboniferous slates and quartzites, and in the bed of Avalanche Creek where it tumbles down into the Merced, the steps here being cut out of a granitic rock.

The presumption that some of the benches and gentle slopes to be noted at the present time in the higher Sierra Nevada are remnants of a gentle surface of Tertiary time does not rest altogether on hypothetical grounds. One very marked bench, indeed, is certainly a portion of the bottom of the valley of the Neocene Tuolumne River. This bench lies on the north side of the Grand Canyon of the Tuolumne, east of Rodger's Canyon, at an elevation of about 8,000 feet. Where this old river valley is cut by Rodger's Canyon, portions of the old surface are perfectly preserved underneath volcanic material (andesite-breccia) of Tertiary age. Farther west, the old valley lies more to the north of the Tuolumne Canyon and hence no longer forms a bench. Where cut through by Piute Creek, this Neocene valley is filled with river gravel and volcanic material, and it next appears exposed to view in Deep Canyon, as a certain portion of Rancheria Creek basin is called. This canyon is practically the Neocene valley of the Tuolumne, from which

[1] Eighth Ann. Rep. U. S. Geol. Surv., Part I, 1889, p. 348.

the lavas and gravels have been washed out by water and gouged out by ice, and has probably been only slightly deepened since the close of the Tertiary. The stream in Deep Canyon has a very slight grade, so that there are frequent stretches of nearly still water.

A section drawn to scale (Plate XXXVI-*A*), across Deep Canyon and the Grand Canyon of the Tuolumne, illustrates the relation of the Neocene and present surface at this point. The dotted line is supposed to represent the old Neocene surface. It exactly represents it at two points; immediately where it intersects the contour of the present surface south of Deep Canyon, and north of the Grand Canyon. The ridge between Deep Canyon and the Grand Canyon is capped with Tertiary lavas, beneath which the old Neocene surface is still intact.

Another interesting feature of this Tertiary river is that it flowed over the present site of Hetch Hetchy Valley, for the ridges both north and south, to the west of Deep Canyon, are too high for it to have taken any other course. The present canyon of the Tuolumne was thus in part initiated in Tertiary time. It is quite probable that this was likewise true of the Merced canyon at Yosemite Valley. It is quite certain that some of the marked benches along the middle fork of the San Joaquin River are of Neocene age for they are covered with Neocene lava flows.

The chief evidence tending to show that there were two glacial epochs consists in the existence of moraines on the summits of ridges farther west than we are able to trace evidences of glaciers in the canyons. This may be noted in the canyon of the Middle Stanislaus, in the Big Trees quadrangle (Plate XXXVI–*C*). The gentle contour of the upper portion of this canyon at the point where the section is drawn appears to represent a former shallow river valley. On the ridges on either side are small moraines and boulders which could easily have been left in their present position if we suppose that during an earlier glacial epoch this shallow valley was filled with ice. In this hypothetical shallow canyon of an early date a rugged and deep

V-shaped canyon has been cut, and nowhere in the V-canyon are there, so far as known, any traces of glacial action, either in the form of the canyon or in the existence of morainal material or of polish on the rocks. The same is true of that portion of the Merced Canyon near Big Meadow, west of Yosemite Valley (See Plate XXXVI–*B*).

In both cases, however, the existence of morainal material on the ridges on either side of these V-shaped canyons shows that the ice at one time covered the area now occupied by these river-cut canyons, and if the present canyon system was then in existence the glacier must have protruded as a tongue still farther west in the lower rugged canyon. Of this there is no evidence. However, the matter needs much more investigation, for at this altitude (2,500–4,000 feet) glacial markings would rapidly disappear, and on account of the steep slopes of the canyons morainal material might easily be removed.

Perhaps the strongest evidence that the inner rugged canyon at this point is of more recent date than the earlier glaciation is its V-shape, characteristic of river erosion. Even after all traces of glacial markings were removed by weathering and all morainal material removed by erosion, we should expect that the U-shape character of the canyon, if it had been occupied by ice, would still be evident.[1]

Another way to account for the V-shape character of the canyons at the western limit of the glaciated area is to suppose that erosion there has been very rapid. The water

[1] In comparing sections of the deep Sierra canyons drawn to scale from the topographic maps of the United States Geological Survey, often no great difference in form is apparent; but when seen on the ground certain differences in details are very plain. Thus, there is usually less talus in a glaciated canyon, it having been removed by the ice as morainal material; the projecting shoulders of the side and hummocks in the floor show rounding; and there is usually more of a floor, or flat space along the bottom. While the deep river canyons exhibit in cross-section a rather flat V-shape, the much talked-of U-shape of glacial canyons is often not so apparent. Such canyons, however, do exist, as for example, that of Bubb's Creek, a tributary of King's River. The U-shape of this canyon is finely seen in a photograph taken by Mr. J. N. Le Conte from near the Grand Sentinel on King's River. Notwithstanding that the difference between cross-sections of the two types of canyons is far from being so marked as the difference between the letters V and U, nevertheless the large floor space of the glaciated canyon gives it a tendency to U-form. Moreover, if exact contour maps of the two types of canyons should be made on the scale of 1000 feet to the inch (about 1/12,000, the present scale of the published maps of the Geological Survey being 1/125,000 or nearly two miles to the inch), the points of difference would probably be clearly apparent in the cross-sections.

from the end of a glacier is filled with sediment and would cut even very hard rock in a comparatively rapid manner. Moreover, the erosion by water of a glaciated canyon would begin as soon as the ice began to retreat. Thus between the beginning of the ice retreat and the present time there would be a considerable period for erosion, and the V-shaped river canyon would gradually eat its way up stream, obliterating the glacial U-form.

Lindgren[1] describes moraines, in position similar to those of the most western moraines of the Stanislaus and Merced, on the ridges enclosing the valley of the Rubicon River, where it cuts across the northwest corner of the Pyramid Peak quadrangle. Lindgren writes:—

> These facts admit of scarcely any other explanation than that the whole basin of the Rubicon River in this vicinity was at one time filled with ice. If it was, the tongue of the glacier in the canyon must have projected into the adjoining Placerville quadrangle, approaching a least elevation of about 3,000 feet. This seems, however, difficult to believe, for the canyon of the Rubicon basin does not in the Pyramid Peak quadrangle present such decided evidence of glaciation as would be expected if the whole deep valley had been filled with ice.

Mr. Lindgren did not think that the facts in this region warranted the assumption of more than one glacial period; but the explanation adopted for the glacial phenomena of the Merced and other canyons would appear to apply equally well here.

8. *Evidence of Glaciation in Yosemite Valley.*

Professor J. D. Whitney is perhaps the only geologist of note who doubted the former presence of glacial ice in Yosemite Valley. It may be well, however, to state specifically the proofs of the occupation of the valley by ice.

Undoubted moraines were found on the valley floor at six points. The one farther east is a medial moraine lying between Tenaya Creek and the Merced near their junction; the others form a group near the western end of the valley.

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[1] Pyramid Peak Folio, Geol. Atlas of the U. S.

The western moraines are in part terminal,[1] and such have caused the formation of meadows and the silting up of the valley. Pebbles are common and nearly all contain boulders of the coarse porphyritic granite, with feldspars three inches or more in length, which is found in place about Lake Tenaya.

There is no evident terminal moraine at the extreme western end of the valley, where it suddenly narrows into a canyon. The moraines observed are of sufficient size, however, to have effected the silting up of the valley; for they rise some feet above the valley floor about them. Moreover, it is quite certain that if we should clear the valley of its alluvial deposits and talus, thus exposing the moraines in their original dimensions, we would find that those now visible were formerly much larger, and that some exist which are now buried from view. There is also what appears to be a small moraine by the Wawona road, at an altitude of 5,000 feet, about northwest of Inspiration Point.[2]

Glacial markings were noted at the following points, beginning at the upper end of the valley. At the top of Nevada Falls, there is glacial polish; also between the Nevada and Vernal falls. Just northwest of Mirror Lake, about forty feet above the water-level, is a patch of glacial polish about thirteen feet in length, showing also striæ well preserved. About 1,200 feet above the lake, on the southeast slope of North Dome, the granite shows groovings in a marked manner. Distinct groovings may be seen on the valley walls at the following points when the light is favorable, and especially after a rain, when the rocks are wet: namely, on the north wall 300 (?) feet above the valley floor, and about 1,000 feet east of Indian Creek; on the north wall 800 (?) feet above the valley floor, and about

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[1] Professor Chamberlin, Third Annual Rept., U. S. Geol. Surv., p. 302, suggests that it is important to distinguish between moraines which mark an important advance of the ice and those which merely indicate a temporary halt or insignificant advance; and he proposes that we should use "terminal moraine" for those of the first class, and "peripheral moraine" for those of the second class. The term is, however, used here in its ordinary sense.

[2] The point here referred to is the one so called on the topographic map of the Geological Survey, and not the one by the Wawona road.

3,300 feet east of Indian Creek; and on the south wall, about 2,300 feet southeast of the post-office, on the east side of the spur leading up to Glacier Point, at an altitude of 500 feet above the valley floor.

On the hill, which is 7,000 feet high, lying nearly three-fourths of a mile southeast of Cathedral Rocks, is a jumble of rocks of small extent somewhat resembling a moraine. It is composed of boulders of dioritic rocks, Bridal Veil granite, and of coarse El Capitan granite.[1] One decomposing boulder of coarse granite contains porphyritic feldspars, some of them over an inch in length, and resembling somewhat the porphyritic granite of Lake Tenaya, boulders of which were found in the moraines on the valley floor. Excepting this porphyritic granite,[2] the bowlders referred to need not be far from the place. The rock immediately underlying the jumble is coarse El Capitan granite, and the dioritic rocks and Bridal Veil granite are both in place on the same spur. It is the rounded form of the boulders and their indiscriminate mixing rather than the character of the rocks that is suggestive of a moraine. There is some polish[3] on the southwest side of the valley, a little below the Wawona road, at an altitude of about 4,800 feet; also some by the road further west, at an altitude of 5,200 feet. The spur that extends north from a little west of Fort Monroe, and which may be said to form the west wall of the valley, shows evidence in its smooth form of having been covered by the glacier. There are perched boulders on it which look as if they have been left there by the ice, but the rock of which they are composed (El Capitan granite) being the same as the rock composing the spur, the evidence is not conclusive. However, we found polish and groovings on the east side of this spur at an elevation of about 4,800 feet, and the direction of the groovings shows that the ice went

[1] Strictly speaking this rock is also a quartz-monzonite, for the amount of orthoclase is at least as large as the amount of plagioclase, and this may likewise be true of the Bridal Veil granite.

[2] This porphyritic granite may have come from a porphyritic facies of an aplite dike, to be found at a point not far away.

[3] The first discovery of this polish was due to Prof. J. C. Branner, whom I desire to thank, also, for other assistance.

over the spur. The preservation of the patches of polish seen on the western walls of the valley is due to their being covered with soil or moss.

The narrow, rugged canyon of the Merced to the west of the valley, when seen after a rain, shows obscure traces of groovings on the south wall, several hundred feet above the river. Further west, we find no more groovings, or polish, but several definite moraines give evidence that the ice extended a little beyond Big Meadow. At Big Meadow there are moraines of some size, at an altitude of from 4,500 to 5,200 feet; and on the south side of Merced Canyon, opposite the Big Meadow moraines, are others something more than 4,500 feet in elevation. On the spur down which winds the trail which leads from McCauley's to the Merced River, there are two small morainal patches, the lower one of which has an altitude of 3,200 feet, the altitude of the river being here only 2,100 feet. This moraine marks the west limit of the great Merced glacier, so far as present evidence goes. The ridge west of Little Crane Creek, to the south of the Coulterville road, was examined for morainal stuff, but none was found. The only objects suggestive of the former presence of morainal material were three well water-worn pebbles picked up on the ridge-top and on its spurs, and these might easily have come from former beds of Neocene River gravel, now completely eroded.

9. *Area Covered by the Yosemite Glacier.*

Having now presented evidence that there was a glacier in Yosemite Valley, let us take a look at its extent or superficial area. This glacier not only occupied all of the present Merced drainage basin above the Yosemite, but received important accessions from overflows of the much larger Tuolumne glacier. Ice entered the valley from Yosemite Creek, Tenaya Creek, Little Yosemite Valley, and possibly Illilouette Creek.

The largest tributary ice-mass without much doubt was that of the Tenaya glacier. For, while the Tenaya Creek drainage basin is small compared with that of the Merced

River above Little Yosemite Valley, yet the overflow from the Tuolumne glacier, comprising, as it probably did, the larger part of the ice that came down the Lyell fork of the Tuolumne River, was so considerable as to form an ice sheet 2,000 feet or more in thickness, extending from Mount Hoffmann to, or nearly to, Cathedral Peak. Nearly all of the huge domes between the Tuolumne Meadows and Lake Tenaya, as well as the domes between the lake and the east end of the Yosemite, were covered by this ice sheet. Probably Mount Watkins was so covered, and pretty certainly both Basket Dome and North Dome; for about one-fourth of a mile north of Basket Dome there was found a boulder of a metamorphic rock, rich in biotite, which undoubtedly came from an area in which such rocks are found on the east slope of Mount Hoffmann. The absolutely bare character of the upper portion of all the domes named suggests that they were cleaned off by ice, but only those in the neighborhood of Lake Tenaya still show definite glacial markings. The probability is that that portion of the Tuolumne glacier which became tributary to the Merced glacier was forced over the low divide between the Tuolumne drainage by the pressure of the enormous ice-mass moving southward from near Mt. Conness.

The next most considerable mass of ice which entered Yosemite Valley came down the upper Merced River, passing through Little Yosemite Valley. The névé basin of this glacier was quite extensive, and this accession of ice was very considerable. According to Professor Whitney, a certain amount of ice from the Tuolumne glacier also came over the divide at the head of Echo Creek; and if such was the case, this ice-mass would contribute to the glacier passing through Little Yosemite Valley. The third tributary to the Merced ice river was the Yosemite Creek glacier. The névé field of this glacier was on the west and north slopes of the high and jagged ridge of which Mount Hoffmann is the culminating point. At an advanced time in the Glacial Period, when the Yosemite had already attained about its present depth, this Yosemite Creek glacier must have fallen in avalanches over the Yosemite Falls

cliff upon the main glacier below. A description by Geikie of a similar example observed by him in Norway will give the reader a picture of the phenomenon as it might have been observed in glacial times in Yosemite Valley. Such glaciers which break into fragments over cliffs and become pressed together again at the base are called "recemented glaciers." Geikie writes:—

> A beautiful example of this again was visited by me at the head of the Jokuls Fjord in Arctic Norway in 1865. * * * The ice from the edge of the snow-field above slipped off into occasional avalanches which sent a roar as of thunder down the valley, while from the shattered ice as it rushed down the precipice clouds of white snow-dust filled the air.[1]

The Illilouette glacier probably likewise reached the valley, but I have obtained thus far no positive evidence that it did so. There were found along Bridal Veil Creek from three to five miles above the falls three small moraines. These appear to be quite old, as the material from which they are composed is much oxidized. They afford the only evidence found that the ice-mass at the head of Bridal Veil Creek ever extended as far north as the points where the moraines are, and no glacial markings of any kind have been found in Bridal Veil Creek basin, except near its head.

Attention has already been called to a small moraine-like mass on the 7,000 foot point southeast of Cathedral Rocks in the Bridal Veil Creek drainage. If this is a moraine it is perhaps more likely that it attained its present position by means of the glacier of Bridal Veil Creek drainage than from that which formerly occupied the Yosemite Valley. The extensive moraines that lie east, north and west of the hill, having an altitude of 9,100 feet two and one-half miles north of Eagle Peak, are to be ascribed to the work of a local glacier moving east, north, and west from this 9,100 foot point. The main ice-mass of this local glacier occupied the drainage basin of Cascade Creek, and as there are two small moraines along Cascade Creek by the Big Oak Flat road, the glacier may have extended down to that point. Whether or not the ice from this source extended still farther and entered the valley there is no evidence.

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[1] Text Book of Geology, 1893, p. 422.

10. *Geological Formations about the Valley.*

Except the Pleistocene deposits, the rocks immediately surrounding Yosemite Valley are entirely granolite.[1] These mostly contain quartz and are ordinarily called granite. The dark cliffs by the Big Oak Flat road are composed of amphibole-gabbro, and the large talus slope, over which the road passes, is formed chiefly of this rock. This gabbro mass is intersected by very numerous, nearly vertical and horizontal joints, and the great size of the talus slope is largely due to the ease with which frost, heat, and water, acting along these joints, have dislodged the fragments. The gabbro is intruded by a number of granitic dikes which, by reason of their light color, are quite noticeable on the cliffs in contrast with the somber tones of the gabbro. Most of these dikes have followed a horizontal joint system.

The quartz-granolites or granitic rocks are of several types which, for the purposes of this paper, may be designated as follows: El Capitan granite, granodiorite, Bridal Veil granite, and quartz-monzonite. The El Capitan granite contains dark mica in abundance to the exclusion of other ferro-magnesian minerals. El Capitan and the cliffs enclosing the west end of the valley are largely made up of this rock, which is probably the oldest quartz-granolite of this part of the Sierra Nevada. Forming a considerable mass in the drainage area of the Yosemite Creek and at Glacier Point is a dioritic rock containing quartz and amphibole which, in the Gold Belt folios, has been called granodiorite. This rock is found in sharp contact with the El Capitan granite and as it contains fragments of that rock it must be of later age. In the area drained by Bridal Veil Creek is a fine-grained white granitic rock which occasionally shows an orbicular structure. This rock forms part of the north face of the north Cathedral Rock, as well as most of the cliffs at the Bridal Veil Falls, but there are mixed with it patches

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[1] Granolite is a general term for all granular igneous rocks, as for example, granite, syenite, and gabbro.

of a dark dioritic rock which confuse the relations at some points. It is designated Bridal Veil granite. Forming the east wall of the valley is a coarse granolite containing scattered prisms of amphibole. As it is found in sharp contact with the basic granodiorite of Glacier Point, and as it is everywhere very uniform in grain and texture, showing little evidence of crushing, it is presumed to be later than most of the other granites. It is genetically related to granodiorite, forming the alkali rich extreme of that rock, but in this paper will be called quartz-monzonite.[1]

The evenly granular texture of the quartz-monzonite lends itself to the process of weathering which has been called exfoliation, and it may be noted that all the domes about the valley, except Sentinel Dome and Boundary Hill, are composed of this rock; that is to say, North Dome, Basket Dome, Half Dome, Cloud's Rest, and Starr King. In addition to these types of granite, each of which forms a considerable mass, there are the usual pegmatite and aplite dikes cutting all of the other granolites and therefore clearly later in age.

The Pleistocene deposits are of three kinds—the talus, the ordinary alluvial deposits formed by stream action, and the moraines. Of these the oldest are the moraines and the youngest the talus. The alluvial deposits may be quite deep, but as there is rock in place at the west edge of the valley by the outlet, this would imply that the valley is a rock-basin filled with detritus. There are no deep wells or borings in the valley, so that any estimate of the depth of the alluvium must rest, for the present, on conjecture.

II. The Joint Systems of the Valley.

Enough has been said in the preceding pages concerning the joints that intersect the granitic rocks to make plain to the reader their general nature and occurrence. It now

[1] Monzonites are granolites containing both orthoclase and plagioclase in abundance. Strictly speaking the El Capitan granite above described is also quartz-monzonite.

remains to examine more definitely the joint planes about the Yosemite and to determine whether they have exerted a controlling influence on the topographic forms.

Vertical Joints.—The strike of the vertical joints and those approximating to verticality was plotted on the geological map. These clearly show that the most abundant vertical joints belong to a system with a northeast strike. Exact measurements were not made of the finely developed joints at Ribbon Falls, or those just east of the cliff at the lower falls of Cascade Creek. In a general way it may be said that vertical joints are more abundant at the Yosemite than at any other deep canyon valley in the Sierra Nevada, so far as my own observation goes. The walls on the south side in particular show vertical jointing splendidly, as may be seen at Sentinel Rock and Cathedral Spires. It is even better shown on the south side of the spur connecting Sentinel Rock with the plateau to the south. The sheeted or joint structure may be seen also at other points on the south wall, between Sentinel Rock spur and Cathedral Rocks. At one point it is brought strikingly to the notice of the observer, since along some of the more thinly sheeted zones the granite has weathered out, leaving narrow, deep, open spaces which are locally known as "the Fissures."

Plate XXXII, representing the spur east of Bridal Veil Creek, shows how erosion along vertical partings has produced the Cathedral Spires and the Cathedral Rocks. Still farther west is the spur which has been referred to before as forming the west wall of the valley, to the northwest of Fort Munroe. Vertical joints penetrate through this spur, and are clearly the cause of the vertical cliffs on the south side of the Merced Canyon west of the valley. On the north side of the valley the vertical jointing is not everywhere evident. It is finely exhibited, however, in the ell just northwest of El Capitan, where the vertical slabs of granite resemble a pile of boards set on edge. Vertical sheeting is also shown in the bluffs west of the top of Yosemite Falls. A highly inclined set of joints may be seen forming the escarpment just east of Yosemite Falls,

but this is not the system which has determined the cliff at the falls. The joints along which this cliff has formed are part of the system which is well developed in the granite just above the falls by the little bridge over Yosemite Creek.

An inspection of the topographic map constructed by the United States Geological Survey brings out the fact that the cliff forming the north face of Half Dome and that east of Illilouette Creek, just below the falls of the same name, have the same trend. The shoulder west of Half Dome shows vertical sheeting apparently parallel to the vertical face of the dome. The Illilouette cliff as seen from the Nevada Falls trail is plainly sheeted or jointed, the joints dipping north at an angle of about 80°. The amphitheater just below Illilouette Falls appears clearly to have been formed by river erosion along this sheeted zone in the granite and presents an extraordinary similarity to the amphitheater at Fall River Falls, in Butte County, California, which has quite certainly resulted from river erosion, since the locality is far below the glaciated region. The escarpment is here primarily due to the vertical sheeting of the granite at the falls. A view of the Fall River amphitheater is given in the Bidwell Bar Folio of the U. S. Geological Survey.

Inclined Joints.—Joints dipping at angles varying from 25° to 50° are not nearly so abundant as the system just described. They are, however, noticeably developed at three points: Bridal Veil Falls, the Three Brothers, and east of Glacier Point. Those at Bridal Veil Falls seem to have been the cause of the V-shape of the ravine of Bridal Veil Creek just above the falls, there being two sets of inclined partings, one dipping west and the other east. At the Three Brothers a westerly dipping system only is strongly developed. This is represented on Plate XXXIII, which is a reproduction of a photograph by Fiske. Nothing can be more evident than that the angular outlines of the Three Brothers are primarily due to these inclined joints. The slope of the spur extending east from Glacier

Point, as seen from near North Dome, appears to have formed along a set of diagonal or inclined joints which dip east about 45°.

Horizontal Joints.—Joints approximating in position to horizontality are to be noted at many places. They are especially well seen on the north side of the valley near Yosemite Creek. Here two terraces clearly marked by lines of trees have resulted from unequal erosion along horizontal joints. At the base of the upper Yosemite Falls is another terrace, and to the east of the falls, near the top of the cliff, may be seen a series of nearly horizontal white granite (aplite) dikes in granodiorite. These dikes were doubtless intruded along the same horizontal joint system.

As has been before noted, the benches over which the river tumbles at Nevada and Vernal falls are formed by unequal erosion along horizontal joints, some of which may be seen on the face of the cliff near the top of the Nevada Falls.

Relation of Joints to Schistosity.—Along some of the joint planes, as for example those at "the Fissures," the rock has been sheared, producing an incipient schistosity, which may be related to the vertical jointing. In general, however, the schistosity, where strongly developed, shows no relation whatever to the joint planes. Thus the granodiorite of the ridge east of Yosemite Creek and of Glacier Point was evidently rendered schistose prior to the development of the main system of joints, for these cut directly across the schistosity.

12. *Formation of Domes.*

No one who has visited the southern Sierra can have failed to be struck by the magnificent granite domes which here and there stand above the general level. Fairview Dome (Plate XXXVII) is an excellent example. It lies just south of Tuolumne Meadows and is about 9,700 feet high, or 1,200 feet above the meadows. In the view it is apparent

that the granite is flaking off in huge scales, which nearly but not exactly conform in shape to the curved surface of the dome. As stated by Branner,[1] these scales overlap like shingles, so that the projection upward of the inner curve of each scale would carry it into the mass of the dome, a fact brought out better by an exfoliating surface near a little lake, known as Royal Arch Lake, that lies northeast of Johnson Lake, in the southeastern portion of the Yosemite quadrangle. The same thing may be seen at the Royal Arches, and on North Dome, in Yosemite Valley.

Whitney thought that exfoliation was due to an original concentric structure in the granite, formed on cooling. Bonney and some German writers adopt the same explanation. Concentric structures certainly exist in what are known as orbicular rocks, where there is a nucleus around which different minerals are deposited in concentric layers, but so far as can be determined from an inspection of the rocks of which the domes are formed, they are usually quite homogeneous in texture, and where they are gneissic or banded the concentric exfoliating shells are as likely to cut across the banding as to conform to it. Another structure seen in some lavas[2] is an original spheroidal structure which may have resulted from flow movements while the lava was quite viscous. In this case the spheroids do not exhibit an orbicular or concentric structure due to the arrangement of the minerals.

Whitney, Bonney[3], and others, however, do not appear to have in mind either of the structures referred to above, but rather a physical structure due to contraction on cooling, perhaps like the perlitic structure of glassy lavas.

In 1869, Shaler[4] called attention to the concentric weathering of granitic rocks and to its superficial nature. Shaler considered that the shells were formed by the heating and consequent expansion of the outer layer, for this would

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[1] Bull. Geol. Soc., America, Vol. VII, 1896, p. 270.
[2] Ransome, Bull. 89, U. S. Geol. Surv., 1898, p. 23.
[3] Quart. Journ., Geol. Soc. London, Vol. XXXII, 1876, p. 149.
[4] Proc. Bost. Soc. Nat. Hist., Vol. XII, p. 289.

tend to separate the heated layer from the cooler portion underneath. He did not regard the presence of water as an essential feature.

Becker, Branner and G. P. Merrill consider the domes as a product of weathering of homogeneous rocks. Becker[1] writes :—

> In my opinion, the great granite domes are simply cases of exfoliation similar, except in scale, to those often observed in basalt and other rocks, and the regular curvature I believe to be due simply to the fact that, measured per unit of volume, the surface exposed is in inverse ratio to the radius of curvature, so that the sharply curved surfaces weather fastest.

Becker also points out that these curved surfaces often cut the gneissic banding, showing exfoliation to be independent of the arrangement of the minerals in the rock-mass. Branner,[2] whose observations were made largely in Brazil, writes:—

> The unequal contraction and expansion of the minerals composing the rock tend to disintegrate the entire mass, while the even annual and diurnal changes and the approximately even penetrations of these changes cause the rocks to exfoliate or to shell off in layers of even thickness like the coats of an onion.

Merrill[3] attributes exfoliation largely to temperature changes, but considers the curved joints or partings in the rock below the exfoliating surface[4] as "the result of torsional strains and once existing are lines of weakness which become more and more pronounced as weathering progresses." Dana[5] attributes concentric exfoliation of many homogeneous rocks (granite, trap, sandstone, etc.) to weathering and not to any original structure in the rocks. Geikie[6] takes the same ground.

In the Yosemite National Park, exfoliation is taking place from nearly all massive granite surfaces. While best developed on the domes, excellent examples may be seen on bare slopes, as that south of the top of the Nevada Falls, and

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[1] Tenth Annual Report U. S. Geol. Surv., 1890, p. 142.
[2] Loc. cit., p. 281.
[3] Rocks, Rock-weathering, and Soils, 1897, pp. 180-184.
[4] Bull. Geol. Soc. Amer. Vol. VII, 1896, p. 245.
[5] Manual of Geology, 1895, p. 127.
[6] Text Book of Geology, 1893, p. 348.

that east of Royal Arch Lake. The Royal Arches themselves in Yosemite Valley are perhaps due to the same process, but here the scales are several feet in thickness.

Half Dome has been called one of the most remarkable rocks in the range from a scenic aspect. It is popularly supposed to represent the half of an enormous dome, the other half of which fell off at some past time. According to Muir, along the base of the vertical portion the stumps of vertical slabs may be seen, which have been successively split off of the vertical face while the rock was being shaped into its present form. As already noted under the section on joints, the shoulders that appear to represent portions of this sheeted zone described by Muir can be seen to be cut by highly inclined or vertical joints. The more simple hypothesis, that the vertical north face of Half Dome has resulted from the scaling off of the vertically jointed granite, and that the residual portion has a dome-form as a result of the exfoliation of an unjointed mass, seems to satisfactorily explain its origin.

13. Formation of the Valley Floor.

If faulting should occur across a canyon and the mass on the down-stream side of the fault be heaved up, it is clear that a barrier would be formed, resulting in the clogging of the drainage and ultimate silting up of the basin, up-stream from the barrier. A valley with flat bottom would thus result. Such a theory might be applied to the Yosemite to account for the formation of the valley floor. However, we have already seen that the small terminal moraines near the west end of the valley probably constitute sufficient barriers to cause the deposit of the sand and gravel forming the valley bottom, providing this deposit is not of great depth.

At the west end of the valley the rock is in place on the side of the gorge and this suggests that the rock-bottom of the valley may not be far below the top of the alluvium; unless we suppose that there was faulting as above

suggested, in virtue of which the rock-mass out of which the gorge is cut was differentially elevated. No evidence of such faulting was found, and although faulting in massive rocks, such as the granites of Yosemite Valley, is not so easily made out as with bedded rocks, yet if such faulting is at all extensive, the granite can not fail to be sheared and cataclastic or crushed structure more or less perfectly developed.

Hetch Hetchy Valley on the Tuolumne River is commonly spoken of as a smaller Yosemite. Like the latter, the river west of it flows through a narrow gorge. This is in places but thirty or forty feet wide, and this outlet is insufficient for the outflow of the water at the time of the melting of the snows in the spring, so that even now the lower end of the valley is a lake for part of the year. There is, beyond all question, a zone of faulting across this gorge at its mouth. The rocks are granites and gneisses and are thoroughly crushed and broken along the larger faults. Specimens of the rock from one of these faults show cataclastic structure under the microscope most admirably. Moreover, in Hetch Hetchy Valley there is no morainal material at its western end, at least not in sufficient amount to dam up the valley. We may therefore conclude that the differential elevation of the west wall of Hetch Hetchy may have formed a rock barrier which dammed back the water and eventually resulted in the deposit of the sediment of the valley floor. [illegible] this it is not meant to imply that the canyon itself was the result of faulting. The Tuolumne canyon like the Merced was doubtless cut out chiefly by water, and afterward cleaned out by a glacier which has left strong groovings at many places on the walls. This glacier filled the valley and extended several miles farther west down the canyon.

14. Conclusions.

The following theories have been advanced to account for the formation of Yosemite Valley:—

1. That it was scooped out by ice. Muir.

2. That it was a river-cut canyon, but that the vertical walls are due to the sapping action of ice. Johnson.

3. That it was formed by a drop fault. Whitney, Reyer, Le Conte? and Russell.

4. That it was formed by river erosion facilitated by strong jointing. Becker, Branner, and Turner.

1. As it has not been shown that ice can dig deep canyons, the first theory does not appear to be well founded.

2. Having obtained good evidence that glacial cirques were made, or at least enlarged, by the sapping action of the ice which they contained, Mr. Johnson felt encouraged to apply the same method to the formation of deep steep-sided valleys. That is to say, while recognizing that the Merced canyon must have been partly excavated by a river, he would suppose that this canyon had the ordinary V-shape of a river canyon, and that the ice by its sapping action cut into the V-slopes, eating backward until vertical cliffs were formed. While sapping action as described by Johnson eats into the slopes of river canyons and results in a U-shape, there is no evidence, so far as my observations go, that it forms high vertical cliffs, except when the rock possesses a vertical structure.

3. The faulting theory is held by some famous geologists. Drop faults, or longitudinal blocks dropped down between two parallel fractures, seem actually to occur in nature, and if one observes the steep walls of the valley as given in the cross-section (Plate XXXVI–*D*) such an origin seems plausible. The vertical joints described in the preceding pages appear, however, to satisfactorily account for the steeply inclined or vertical walls. Moreover, it is difficult to understand how faulting on so extensive a scale can have taken place, and yet end so abruptly at the east and west ends of the valley, unless, indeed, we regard Tenaya Canyon as part of the faulted area or *graben*. There is, to be sure, a sheeted zone, as already described, just north of Half Dome, and some faulting may have occurred along this zone; but in general the well exposed rocks of

Tenaya Canyon are massive and do not suggest extensive faulting. A *graben* with a depth of 4,000 feet would probably have a much greater longitudinal extent than the length of Yosemite Valley.

4. We are now brought down to the fourth hypothesis, which would place the Yosemite in the same category with the other rugged and deep canyons of the Sierra. The fact that Hetch-Hetchy Valley was initiated in Tertiary time has already been noted. While we have no positive evidence, this is likewise probably true of the Yosemite, for nearly all of the rivers of the southern Sierra Nevada appear not to have been filled with lavas and displaced during the late Tertiary, as was the case farther north. There may thus have been a river valley on the site of the present Yosemite in the beginning of the Pleistocene, and this valley may easily have been a thousand feet deep at that time. This lessens the difficulty of accounting for the present depth of the Yosemite and of other canyons of the southern Sierra.

If Yosemite Valley were unique, some special origin might be sought for it. As a matter of fact there are several valleys in the Sierra Nevada similarly situated and sufficiently similar in configuration to suggest that they all originated in the same manner. As has been noted by Le Conte and others, these valleys lie in about the same position relative to the crest of the range. Le Conte refers to a valley near Sugar Loaf on the South Fork of the American River (Pyramid Peak quadrangle) as being comparable to the Yosemite. A small valley on the Middle Stanislaus at the mouth of Niagara Creek (Dardanelles quadrangle) has precipitous walls and a narrow outlet. Mr. Becker has referred (loc. cit., p. 35) to a gorge which seems to him an incipient Yosemite. Another canyon which under favorable circumstances would widen out into a Yosemite is the lower part of Sawmill Canyon (See Plate XXXVIII). The granite is here divided into a number of vertical sheets by an east and west joint system, and along these joints vertical cliffs, over 2,000 feet high, have formed. This was the work of a small stream aided by heat and frost, for the glacier that

formerly occupied the canyon, while it extended to the west or up-stream base of the cliffs, seems never to have attained any considerable thickness at this point. Had Sawmill Creek been a river, a Yosemite would have resulted.

Hetch Hetchy Valley on the Tuolumne River, with an altitude of 3,660 feet, has already been mentioned. If a similar valley exists on the San Joaquin River, the next stream south of the Merced, it has not yet been described, but on the Middle Fork of the King's River is Tehipite Valley, with an altitude of about 4,200 feet. It is surrounded by high cliffs and there is here also a magnificent dome, a view of which is reproduced in a paper on Tehipite Valley by J. M. Stillman.[1] According to Mr. J. N. Le Conte, this dome rises 3,000 feet above the valley. On the South Fork of King's River, situated relatively like the valleys above noted, is the Grand Canyon of King's River. No one except those holding Muir's views can doubt that water is the main agent in cutting the deep canyons of the range below the limit of glacial ice. This would allow river action to form that part of the Merced canyon west of Big Meadow, and thus the river, without the aid of ice or of drop-faulting, has cut a canyon 3,500 feet deep. As previously suggested, it is difficult to see how the river, having in its lower reaches dug out a deep canyon, should suddenly lose this erosive power on reaching the glaciated region, for although the ice sheet is represented as protecting the land from extensive erosion, it has been shown that the ice probably did not occupy the glaciated zone during all of early Pleistocene time. Much more natural is it to suppose that the rivers have in the main formed the canyons they occupy from their source to the Great Valley.

That some faulting has occurred along the sheeted or jointed zones of granite about the Yosemite is probable, but it is thought that this has resulted rather in a more thorough shearing of the granite than in the dropping down of

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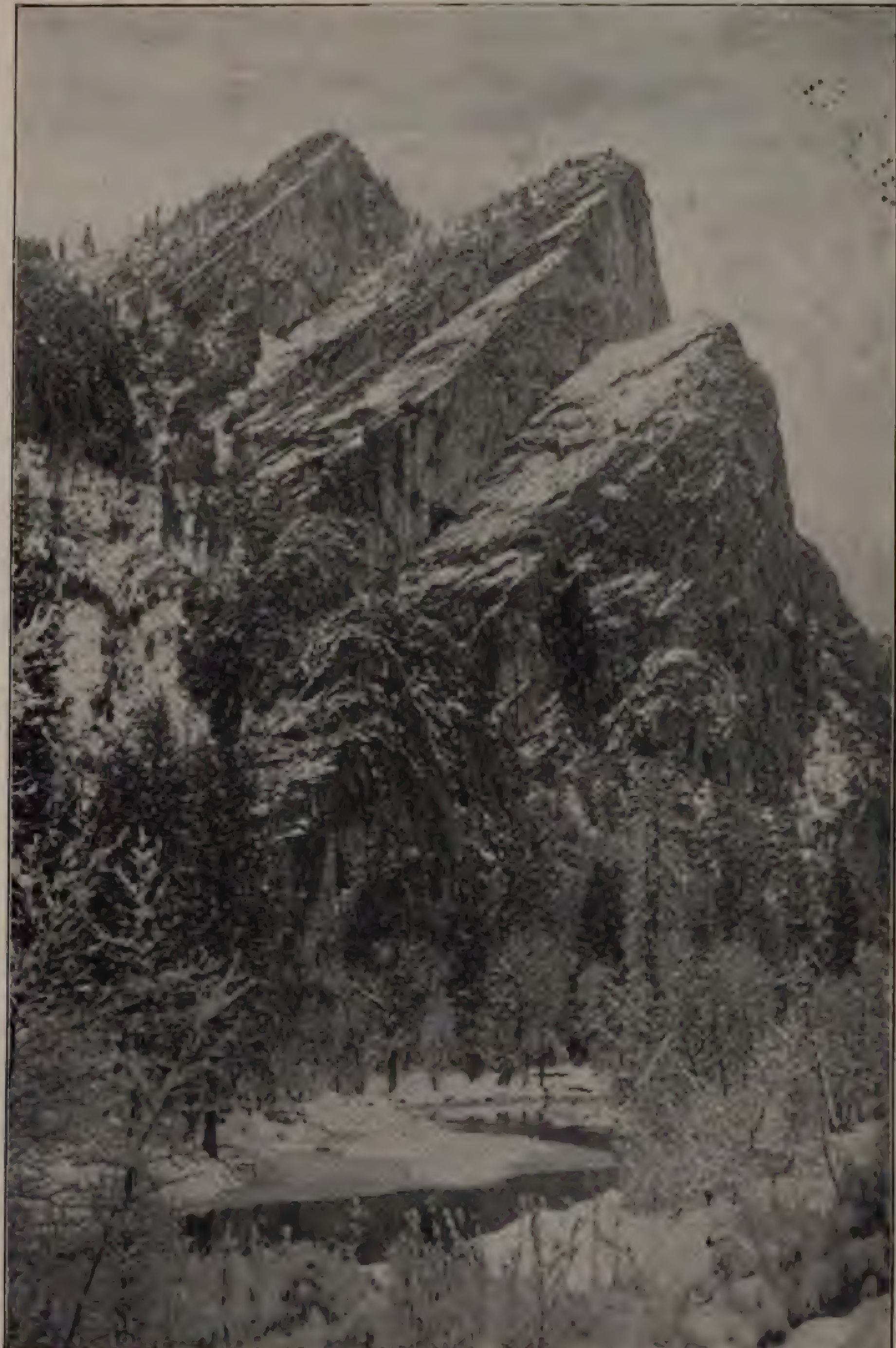
[1] Sierra Club Bull., Vol. II, 1897, Plate VII.

wedges. Along such a sheared zone the streams would rapidly deepen their beds. Even where the rocks are not sheared, but merely intersected with vertical joints, it is easy to see how, as erosion progressed, the slabs would crumble or tumble off along the joint planes, leaving vertical faces. If now a tongue of ice should pass through the valley and clear out the talus and other detritus and round off the projecting shoulders and spurs, and as it retreats leave terminal moraines as barriers to form the valley floor, we seem to have sufficient means for the accomplishment of all we now see in Yosemite Valley.

TABLE OF ILLUSTRATIONS.

Tenaya Canyon, Looking Northeasterly from near Glacier Point.

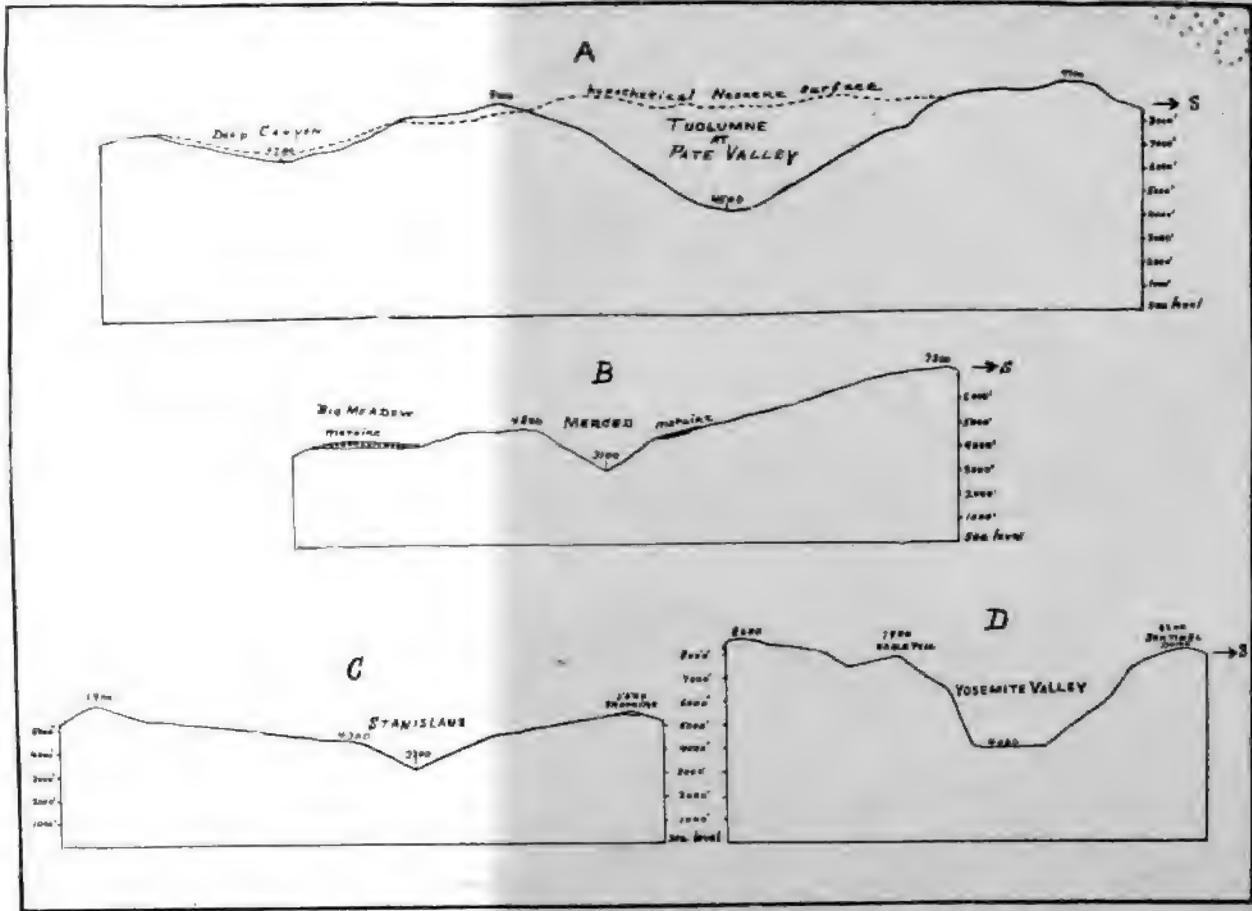
Cathedral Rocks Spur from the East, Showing Erosion along Vertical Joints.



The Three Brothers, Showing Inclined Surfaces Formed by Erosion along Inclined Joints.

Lake Washburn, a Rock Basin Dug Out by a Glacier.

Wall of Glacial Amphitheater or Cirque at the Northeast Base of Merced Peak.



Sections across Canyons.—Horizontal and vertical scale the same.

Fairview Dome, South of Tuolumne Meadows, Showing the Shelling Off or Exfoliation of the Granite in Huge Scales

Vertically Jointed Cliffs on the South Side of Sawmill Canyon.

Rock Basin, Three Feet in Diameter, Formed by the Unequal Weathering of Granite.

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The Comparative Stratigraphy of the Marine Trias of Western America

BY

JAMES PERRIN SMITH

WITH TEN PLATES

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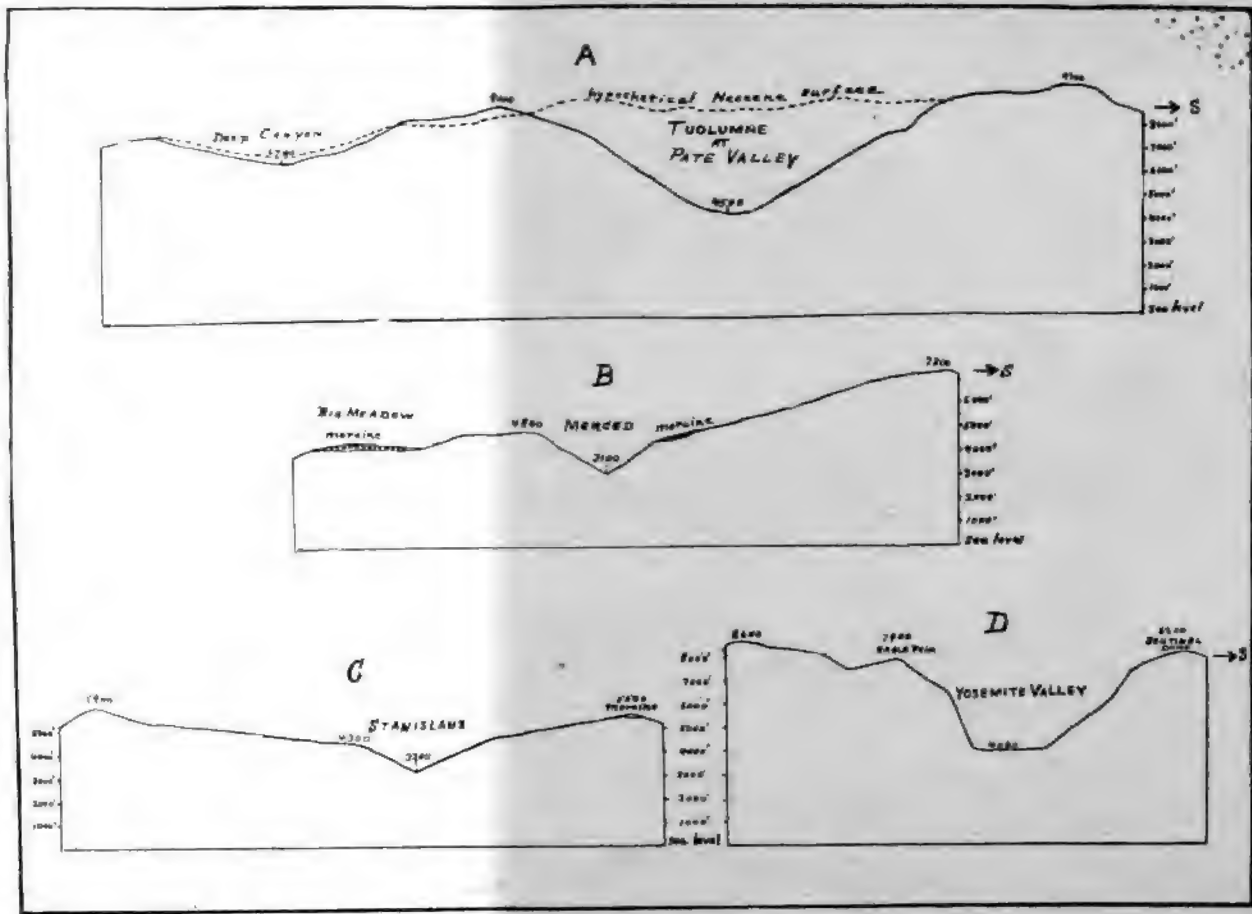
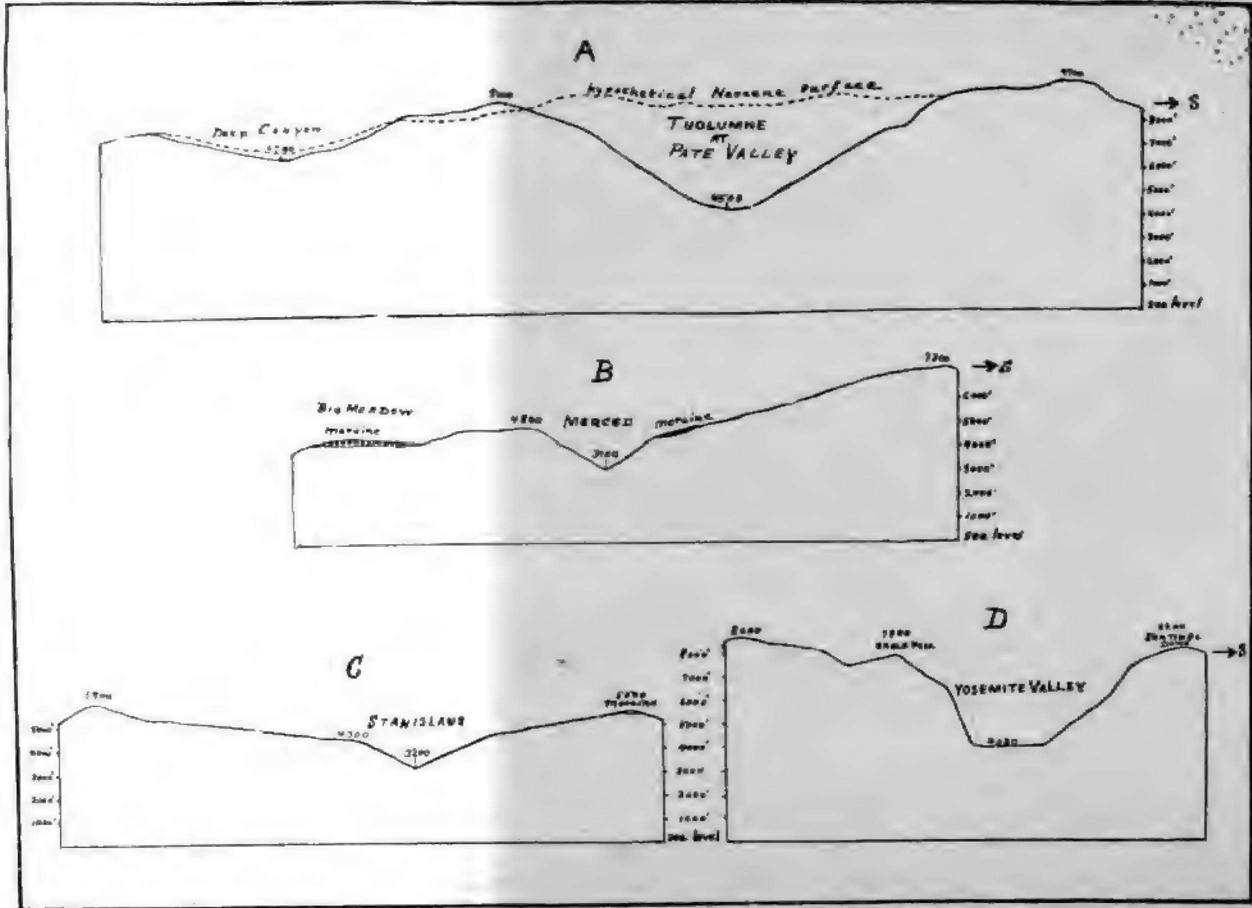


Sections across Canyons.—Horizontal and vertical scale the same.



Sections across Canyons.—Horizontal and vertical scale the same.

THE GEOGRAPHY OF THE TRIAS.

THE Triassic system took its name from the peculiar three-fold development in the Germanic basin, in which at the base are beds of sandstone, in the middle are massive and shaly limestones, and at the top, clay shales and thin beds of quartzite. This basin was an interior sea, wholly cut off from the outside world during the greater part of its existence; but its sediments are so accessible to students of European stratigraphy that its local names have been used to designate subdivisions of the Trias all over the world. And ever since the extension of local names became customary, geologists have been sorely puzzled to know how to identify the pelagic equivalents of Buntsandstone, Muschelkalk, and Keuper, since those inland deposits seldom contain any of the open-sea species.

Instead of being the type of the Trias, the Germanic basin sediments are the exception, and the type is to be sought in strata that were laid down along the borders of open seas. These have long been known in the limestones and shales of the Alps, Himalayas, Salt Range, Siberia, and western America, but the nomenclature has always been obscured by local names. There is therefore an urgent need for some uniform system of nomenclature by which Triassic open-sea sediments may be correlated directly with each other, without reference to the old and unrecognizable divisions.

The Vienna geologists, Dr. E. von Mojsisovics, Dr. W. Waagen, and Dr. C. Diener, have attempted to give the desired classification, in a paper entitled "Entwurf einer Gliederung der pelagischen Sedimente des Trias-Systems" (27). The authors divide the Triassic pelagic deposits into four series, Scythic, Dinaric, Tirolic, and Bajuvaric; and these again into stages and substages, and further into zones, the latter having usually only a local value. The correlation table published in the present paper is adapted from that of these authors, as is also the nomenclature of the subdivisions.

The principal regions where Triassic faunas are known are the Alpine region, the Himalayas and Salt Range, northern Siberia, and western America. The faunas of these countries seem to be so different that they may be taken as representing ancient geographic regions. In Mesozoic times a sea stretched through southern Europe, eastward to the Himalayas; this was years ago called by Neumayr the "Central Mediterranean," and Suess has proposed for it the name Thetys, or more properly, Tethys. Along the western borders of the Tethys were deposited the Triassic sediments of the Alps, Spain, southern Italy, the Balearic Islands, Sicily, Hungary, the Balkan Peninsula, and Asia Minor. This region was named by Mojsisovics the Mediterranean Trias province. Most of the faunas of the Trias, from near the base to the top, are represented in this region.

To the east the Tethys spread out to the waters of the Indian region, in which the sediments of the Himalayas and the Salt Range accumulated, bounded on the south by the land mass of which southern India is but a remnant. The Indian waters joined on the east and southeast with the great Arctic-Pacific Trias ocean, or Arctis of Mojsisovics, along the borders of which were deposited the sediments of northern and eastern Siberia, Spitzbergen, Japan, Rotti, New Zealand, New Caledonia, Peru, and western North America. But in this ocean region there were many provinces as yet unknown, or only vaguely defined.

The open-sea Triassic deposits known at present may be grouped in four geographic faunal regions, the Mediterranean, the Oriental, the Arctic-Pacific, and the American.

The Mediterrean Region. Triassic deposits of the Mediterrean region were described first from the Germanic inland sea and the Alpine province, and afterwards from the Pyrenees, the Balearic Islands, Sicily, southern Italy, Hungary, the Balkan Peninsula, the Gulf of Ismid in Asia Minor, and from near the mouth of the Araxes in Armenia. In all these places the faunas are of the same general type, but show provincial differences. This is especially true of

the Germanic inland sea, which was cut off from the outside ocean during the greater part of the Trias, and is characterized by a distinctly provincial fauna. But even this sea was not always a closed basin, for Dr. A. Tornquist (35 and 36) has shown that during the time of the upper Muschelkalk, or Buchenstein beds, a connection was established temporarily with the open sea, or Tethys, permitting emigration of *Ceratites nodosus* from the basin into the waters of the southern Alps. In its new surroundings this species varied until it gave rise to several new varieties or mutations, but all distinctly recognizable as belonging to the group of *Ceratites nodosus.* This discovery first enabled the certain correlation of the Alpine and Germanic upper Muschelkalk, for up to this time the Buchenstein beds and their equivalents all over the world had been considered at the bottom of the Upper Trias. This revision affects not merely the Alpine province, but also the beds of Japan and western America, where similar faunas are found.

Among the most characteristic features of this region is the prevalence of Tirolitinæ in the Lower Trias, while members of this group are unknown in this time in any other region. The same thing is true of the occurrence of *Hungarites*, which was common in the Mediterranean region from the upper Permian onward, reached India in the Lower Trias, but did not appear in the other regions until near the beginning of the Middle Trias. Among the negative characteristics may be noted the absence, during the Lower Trias, of *Flemingites*, *Ophiceras*, and *Otoceras*.

These differences did not persist throughout the Muschelkalk, for *Hungarites* made its way into the outer regions, and *Meekoceras* became common in the Alpine province, although by this time the genus had undergone many modifications, and was represented at least by different subgenera.

In the various provinces of the Mediterranean region, the three subdivisions of the Trias are very unequally represented. Distinctive cephalopod faunas of the Lower Trias are known only in the Alpine province, in the Balkan

Peninsula, and in Armenia. Characteristic faunas of the Middle Trias are known in the Germanic province, the Alpine province, the Pyrenees, the Balkan Peninsula, and in the Gulf of Ismid in the Sea of Marmora. Typical cephalopod faunas of the Upper Trias are known in the Mediterranean region only in the Alpine province, and from Balia Maaden in Asia Minor. The strata in the Pyrenees that have been ascribed to this age probably belong to the Buchenstein epoch, the upper part of the Muschelkalk.

The waters of the Mediterranean region extended from the Pyrenees on the west, to the Araxes River, in Armenia, on the east, although probably not extending all over this expanse at one time. The greatest expansion of the waters of this region occurred in the Muschelkalk, when a characteristic fauna extended from Spain to the Sea of Marmora, when cephalopods made their way from the Germanic inland sea into the Alpine province, and when certain elements were common to the Mediterranean, the Oriental, and the Arctic-Pacific regions.

The cephalopod faunas of the Mediterranean region have been fully described and illustrated by E. von Mojsisovics, in "Die Cephalopoden der Mediterranen Triasprovinz" (21), and in "Das Gebirge um Hallstatt" (22 and 23), Parts I and II. These works have served as a standard and means of comparison of Triassic faunas, wherever such have been found.

Dr. E. Philippi (29*a*) has recently published a monograph on the Ceratites of the Muschelkalk of the Germanic basin, in which all the ammonites of that province are described.

The Oriental Region. Triassic faunas are known in the Oriental region chiefly from the Himalayas and the Salt Range in India, although outliers also occur in Afghanistan and the Pamir. The entire Triassic stratigraphic column is represented in this region, although only parts of it at any one place. The Lower Trias is best developed in the Salt Range, the Middle Trias poorly, and the Upper Trias scarcely at all. In the Himalayas, on the other hand, the Lower Trias is not so well developed as in the Salt Range,

but the Middle and the Upper Trias are nearly complete, the supposed profound breaks in the sedimentation having been shown by Dr. A. von Krafft (15) to be absent.

The Oriental region furnishes the world's type of open-sea faunas of the Lower Trias, and the cephalopods of this epoch are incomparably rich in contrast with the scanty representation of the Werfen beds of the Mediterranean region.

During the Lower Trias the Oriental region was cut off from the Mediterranean, but was intimately connected with the Siberian province of the Arctic-Pacific region, and with the American region, as attested by the absence in all these of the Tirolitinæ of the Mediterranean, and the abundance of *Flemingites*, *Ophiceras*, *Meekoceras*, *Aspidites*, and other members of the Meekoceratidæ. Several species are common to the Indian and the Siberian provinces, as *Ceratites subrobustus* Mojsisovics, *Meekoceras boreale* Diener, *Ophiceras sakuntala* Diener, *Hedenstrœmia mojsisovicsi* Diener; and several are represented in the American region by either identical or closely related forms.

During the Middle Trias the Oriental region still shows its connection with the Arctic-Pacific, and begins to show some slight relationship with the Mediterranean region, with a few very doubtful species in common. The former intimate connection with the American region seems to have been interrupted with the beginning of the Muschelkalk.

The Upper Trias is best represented in the Himalayan province of the Oriental region; the Karnic stage contains the *Tropites subbullatus* fauna, common to the Alpine province and the western American beds, with a possible identity of species with both regions.

The cephalopod faunas of the Lower and the Middle Trias of the Oriental region have been described by W. Waagen (38), and by C. Diener (3 and 4), in three large monographs, in which all known species of that region, old or new, are described and figured. These works have become a standard and means of comparison of the Lower Triassic faunas of all the world.

The descriptions of the cephalopods of the Upper Trias of the Oriental region have been published by E. von Mojsisovics (24) in monographic form in the Memoirs of the Vienna Academy of Sciences, and this work has since then been translated into English and republished in the Memoirs of the Geological Survey of India.

In addition to the previously mentioned characteristics of the Oriental region, it may be noted that *Hungarites* and *Ptychites* occur well up in the Upper Trias, while in the Mediterranean region *Ptychites* does not occur after the Muschelkalk, and *Hungarites* has never been found above the Longobardic stage, zone of *Protrachyceras archelaus*, the base of the Upper Trias.

The Arctic-Pacific Region. Triassic deposits are known in the Arctic-Pacific region in Spitzbergen, in northern Siberia near the mouth of the Olenek River, in eastern Siberia near Vladivostok, in Japan, near Tonquin in southern China, and on the islands of New Caledonia, Rotti in the Indian Archipelago, and New Zealand. In all probability this is not one faunal region, but is made up of many heterogeneous provinces; but at present our knowledge of the various faunas, except those of the Ussuri and the Olenek provinces, is too meager to enable any geographic separation. Mojsisovics has included in this region the Triassic deposits of western America; but further investigation has shown that the relations of the faunas of Idaho, California, Nevada, and British Columbia to those of Asia are not sufficiently intimate to justify a union in one geographic faunal region, at least for more than short epochs.

Lower Triassic faunas are known in the Arctic-Pacific region only from Ussuri Bay in eastern Siberia, and from near the mouth of the Olenek River in northern Siberia. The Olenek province is characterized by the abundance of *Dinarites* of the group of *D. spiniplicati*, *Sibirites*, and *Ceratites* of the group of *C. subrobusti*. *Ceratites subrobustus* Mojsisovics and *Hedenstrœmia mojsisovicsi* Diener are common to these beds and the *Subrobustus* beds of the Oriental region, and serve as criteria in correlation.

Middle Triassic or Muschelkalk faunas are known on Spitzbergen, near Mengiläch on the Olenek River, in the *Monophyllites* beds of Ussuri Bay in eastern Siberia, and in the lower part of the Rikusen beds of Japan, which seem to be the equivalents of the Ladinic series of the Mediterranean region. These strata are characterized by *Ptychites*, *Hungarites*, *Beyrichites*, *Ceratites*, and *Monophyllites*.

Upper Triassic cephalopod faunas are described only from the Rikusen beds of Japan, where the upper portion may be the equivalent of the Wengen beds of the Alps; they may also be represented in the *Stenarcestes* beds of New Caledonia, and in the *Juvavites* beds of Tonquin, China. Pelecypod faunas of this age are known in Spitzbergen, northeastern Siberia, Japan, New Zealand, and Timor, where *Halobia* and *Pseudomonotis* are the chief forms.

The faunas of the Arctic-Pacific region have been described in monographic form by E. von Mojsisovics (20 and 25) and C. Diener (5). In these works the comparative stratigraphy and the distribution and relationships of faunas in the various provinces are given in great detail.

The American Region. In the American region marine Triassic deposits are known in Alaska, Queen Charlotte Islands, British Columbia, California, Nevada, Idaho, and Peru, with some doubtful beds in Mexico. Marine faunas of Lower Triassic age have been described only from the Aspen Mountains of southeastern Idaho, and the Inyo Range of eastern California. These two localities have a number of species in common, and also several that occur in the Oriental region, with several species nearly related to forms in the Siberian province of the Arctic-Pacific region. Nearly every characteristic genus of both the Arctic-Pacific and the Oriental regions, with the exception of *Otoceras*, has been found either in the Aspen Mountains or the Inyo Range. These include several genera that have been known hitherto in only one or the other of the two great faunal regions. But the American region seems to have been quite as closely connected with these as they

were with each other, and all three regions seem to have been cut off from the Mediterranean during the greater part of the Lower Trias.

Marine faunas of the Muschelkalk, or Middle Trias, are known at present in the Great Basin, the Humboldt Mountains of Nevada, and the Inyo Range of eastern California, where the occurrence of *Ptychites*, *Hungarites*, and *Acrochordiceras* in both provinces, and in addition of *Beyrichites*, *Balatonites*, and *Ceratites* in Nevada, place the determination of their age beyond doubt. The top of the Pitt shales in Shasta County, California, also belongs here.

Upper Triassic faunas are certainly known in this region only in northern California, Nevada, and British Columbia.

Detailed descriptions and figures of marine Triassic faunas of the American region have been published by W. M. Gabb (9), in the Reports of the Geological Survey of California; by F. B. Meek (18), from the Humboldt Range of Nevada; by C. A. White (40), from the Aspen Mountains of Idaho; and by J. F. Whiteaves (42), from British Columbia and Queen Charlotte Islands.

The most striking characteristics of the American region are the commingling in the Lower Trias of Arctic-Pacific and Oriental types, such as *Prosphingites*, *Ussuria*, *Hedenstrœmia*, *Pseudosageceras*, *Flemingites*, *Ophiceras*, and *Meekoceras;* the commingling in the Middle Trias of Arctic-Pacific and Mediterranean types; and the occurrence in the Upper Trias of a distinctly Alpine fauna, such as *Tropites subbullatus* and its allies, intermingled with *Trachycerata*.

THE SUBDIVISIONS OF THE TRIAS.

The accompanying correlation table is based on the stratigraphic work of E. von Mojsisovics, W. Waagen, C. Diener, G. von Arthaber, A. von Krafft, A. Hyatt, and the writer. It is an attempt to represent in graphic form the occurrence and relations of the marine Triassic strata in all regions, and to give a means of comparison with standard and typical sections.

For many years students of Triassic stratigraphy were compelled to use in interregional correlation the lithologic nomenclature of the deposits of the Germanic basin, the faunas of which were scanty and of only local occurrence. The only faunas known outside the Germanic basin were in the Alpine province, but even here the complete series was not well represented, and the order of superposition of the faunas not clearly established. It was not until stratigraphic and paleontologic studies were made in the Trias of extra-Mediterranean regions that a clear idea was obtained of the succession and relationships of the Mediterranean faunas, especially of the Lower Trias. Hence it is that in the nomenclature of stages and formations we find such a mixture of Tyrolian, Italian, Indian, and Siberian names; for the stages were named from their most typical occurrence, in whatever part of the world it happened to be; and these local names have become, by common usage, interregional or international terms for strata with a similar or a correlative fauna.

The nomenclature used is, with some slight changes necessitated by later studies, that of Mojsisovics, Waagen, and Diener (27), in their attempt at a systematic classification of the open-sea Triassic sediments and faunas of the world. Such changes are due to Dr. A. Tornquist's finding *Ceratites nodosus* in the Buchenstein horizon of the southern Alps, and to the agreement of a majority of Austrian geologists to substitute Ladinic for Noric, and Noric for Juvavic in the Alpine section. These two changes affect the stratigraphic nomenclature of Japan, California, and Nevada, as well as of the Mediterranean region.

THE LOWER TRIAS OR SCYTHIC SERIES.

Brahmanic Stage. The lowest series of the Trias was named by Waagen and Diener (27) from the region of its most typical development in Asia. It is divided into two stages; an older, or Brahmanic, named from India, where its fauna is best developed; and a younger, or Jakutic,

	Series		Stage	Substage	Interregional Zone	Mediterranean Region: Germanic Province	Mediterranean Region: Alpine Province		Arctic-Pacific R		
Upper Trias	Bajuvaric		Rhaetic			Rhaet		Koessen beds			
Upper Trias	Bajuvaric		Noric	Sevatic	Zone of *Pseudomonotis subcircularis*, in Siberia, Alaska, Canada, California, Peru, and Indian Ocean	Keuper		Noric limestones of Hallstatt	*Pseudomonotis oc* beds of Japan, no Siberia, and Ind Ocean		
Upper Trias	Bajuvaric		Noric	Alaunic							
Upper Trias	Bajuvaric		Noric								
Upper Trias	Tirolic		Karnic	Tuvalic	*Tropites subbullatus* fauna in Alps, Himalayas, and California	Keuper		Sandling beds with *Tropites subbullatus*			
Upper Trias	Tirolic		Karnic	Julic	*Halobia superba* in Alps and California			Raibl beds with *Trachyceras aonoides*			
Upper Trias	Tirolic		Karnic	Cordevolic				St. Cassian beds with *Trachyceras aon*			
Upper Trias	Tirolic		Ladinic	Longobardic	*Daonella lommeli* fauna in Alps and Himalayas			Wengen beds with *Protrachyceras archelaus*			
Middle Trias or Muschelkalk	Tirolic	Upper Muschelkalk	Ladinic	Fassanic	Zone of *Anolcites* in Alps, Himalayas, Japan, and Nevada	Upper Muschelkalk with *Ceratites nodosus*		Bucenhstein beds with *Ceratites nodosus* and *Protrachyceras curionii*	Ceratite beds of J with *Ceratites japonic* *Anolcites gottsche* *Danubites naum*		
Middle Trias or Muschelkalk	Dinaric	Middle Muschelkalk	Anisic	Bosnic		Middle Muschelkalk	Upper Reifling beds	Limestone of Han Bulog with *Ceratites trinodosus* in eastern Alps and the Balkan Peninsula	Sandstones of Ussuri Bay in Siberia, with *Monophyllites sichoticus*	Mengilaech beds of Siberia with *Hungarites triformis*	*Dao* limest Spitzb
Middle Trias or Muschelkalk	Dinaric	Lower Muschelkalk	Anisic	Balatonic		Lower Muschelkalk with *Hungarites strombecki*	Lower Reifling beds	Lower Muschelkalk with *Ceratites binodosus*			
Middle Trias or Muschelkalk	Dinaric	Lower Muschelkalk	Hydaspic	Hydaspic	*Ceratites subrobustus* in northern Siberia, Salt Range, and Himalayas			Beds of the Gulf of Ismid in Asia Minor			*Posido* limest Spitzb
Lower Trias	Scythic		Jakutic		*Flemingites* fauna	Buntsandstone	Werfen beds	Calcareous beds with *Tirolites cassianus* and *Pseudomonotis clarai*	Olenek limestone northern Siber		
Lower Trias	Scythic		Brahmanic		Zone of *Meekoceras* fauna in eastern Siberia, Salt Range, Himalayas, Idaho, and California			Unfossiliferous	*Proptychites* beds Ussuri Bay in east Siberia, with *Meeko* *boreale, Ophicer* *sakuntala, Proptyc* *hiemalis, Pseudosa* *ras, and Ussuri*		

Oriental Region		American Region			
...alayas	Salt Range	California	Nevada	Idaho	Britis... Columb...
		Rhaetic plant beds of Plumas County, California			
...estones of ...yas, with ... *Halorites*, ...*auerites*		*Pseudomonotis subcircularis* slates	*Pseudomonotis* beds, with *Rhabdoceras* and *Arcestes*		*Pseu... mono...* bed...
		Hosselkus limestone of Shasta and Plumas counties: *Spiriferina* bed	Star Peak limestone without determinable fossils		
...es limestone ... Kalipani		*Juvavites* beds			
		Tropites subbullatus beds			
...*lla* beds with ...*achyceras* ...*ticum* and ...*chyceras* cf. ...*onoides*		*Halobia superba* beds			
		Black calcareous argillites with *Protrachyceras homfrayi*			*Trach... cera...* bed...
...eds with ...*chyceras* cf. ...*ielaus* and ...*lla lommeli*		Pitt Shales of Shasta County: Black siliceous shales of Silverthorn's Ferry, with *Anolcites* cf. *whitneyi*, *Ceratites* aff. *humboldtensis*, *Arcestes* (*Joannites*) sp.	Daonella limestone of the West Humboldt Range: Limestones with *Ceratites*, *Beyrichites*, *Hungarites*, *Balatonites*, *Ptychites*, *Anolcites*, *Protrachyceras*, *Joannites*, *Orthoceras*, *Daonella*, *Danubites*, *Sageceras*		
...eds with ...*lla lommeli* ...*otrachyceras* ...*ladinum*					
...uschelkalk ...ith ...*s rugifer*	Bivalve beds	Unfossiliferous siliceous shales		Aspen beds of the Aspen Mountains: Pelecypod beds, without cephalopods	
...uschelkalk ...ith ...*prahlada* ...*subrobustus*	Ceratite Formation: Upper Ceratite limestone	Ceratite limestone of the Inyo Mountains: Upper, black beds with *Hungarites*, *Ptychites*, *Acrochordiceras*, and *Tirolites*	No fossils known		
...s with ...*stræmia* ...*vicsi* and ...*tes nivalis*	Ceratite sandstone, with *Ceratites*, *Acrochordiceras*, *Aspidites*, and *Flemingites*	Unfossiliferous shaly limestone, about 800 feet thick			
... beds, with ...*Ophiceras*, ...*ychites*, ...*s*, *Danubites*, ...*Flemingites*, ...*dlicottia*	Ceratite marls, with *Meekoceras*, *Proptychites*, *Ceratites*, and *Clypites*	Lower, gray limestone, with *Meekoceras gracilitatis*, *Koninckites mushbachanus*, *Gyronites aplanatus*, *Nannites*, *Pseudosageceras*, *Aspidites*, *Danubites*, *Proptychites*, and *Ussuria*		*Meekoceras* beds, with *Meekoceras gracilitatis*, *Koninckites mushbachanus*, *Gyronites aplanatus*, *Nannites*, *Pseudosageceras*, *Aspidites*, *Flemingites*, *Ussuria*, and Columbites beds	
	Lower Ceratite limestone, with *Meekoceras*, *Proptychites*, and *Lecanites*				

named from northern Siberia, where its typical fauna was first described. Diener and Waagen further proposed to divide the Brahmanic stage into two substages, an older, or Gangetic, and a younger, or Gandaric. The Gangetic substage was supposed to be represented only by the *Otoceras* beds of the Himalayas, and the Gandaric found its prototype in the Lower Ceratite limestone and the Ceratite marls of the Salt Range. This was on the supposition that the two faunas were distinct, and that the *Otoceras* beds represented the very base of the Trias, while the Salt Range beds were supposed to begin higher up in the series, with an unconformity separating them from the Permian *Productus* limestone. But very recently F. Noetling (28 and 29) has shown that there is no unconformity in the Salt Range, separating the *Productus* limestone from the Lower Ceratite limestone, and that the *Otoceras* fauna is very probably the equivalent of the uppermost fauna of the *Productus* limestone. There is therefore no reason for a subdivision into the Gangetic and Gandaric substages. Noetling even went so far as to assert that because of the continuity of the sedimentation and the faunas with the Permian beds, the entire Ceratite formation should be grouped with the Paleozoic and not with the Trias. That this view is untenable is shown by the discovery of a Lower Triassic, Werfen, fauna of pelecypods, gastropods, and brachiopods in the lower part of the Ceratite formation of the Salt Range (39). It is therefore evident that in the Oriental region the chasm between the Paleozoic and the Mesozoic is bridged over, but we must draw an arbitrary line below the equivalents of the Werfen beds (6).

The Brahmanic stage is best represented in the Himalayas and Salt Range of the Oriental region, in the *Proptychites* beds of Ussuri Bay in eastern Siberia, and in the *Meekoceras* beds of the Aspen Mountains of Idaho and the Inyo Range of California. Cephalopod faunas of this stage are not known in the Mediterranean region. This stage is characterized by the occurrence of *Dinarites*, *Danubites*, *Nannites*, *Proptychites*, *Prosphingites*, *Pseudosageceras*,

Ussuria, *Flemingites*, *Ambites*, *Kymatites*, *Lecanites*, *Prionolobus*, *Gyronites*, *Aspidites*, *Meekoceras*, *Clypites*, *Ophiceras*, *Otoceras*, and *Medlicottia*. The two latter genera begin in the Permian, *Medlicottia* becoming scarcer, and *Otoceras* more abundant in the Lower Trias. It now seems probable that the bed with *Otoceras* and *Medlicottia* may belong to the upper Permian.

Jakutic Stage. The Jakutic stage is most typically developed in the Salt Range of India, where it comprises the Ceratite sandstone. In the Himalayas it is represented by the *Subrobustus* beds, with a fauna almost identical with that of the Ceratite sandstones. In northern Siberia, where it was first described, it consists of the lower black calcareous beds of Mengilaech near the mouth of the Olenek River. In former publications the writer (32 and 33) placed the *Meekoceras* beds of Idaho in the Jakutic stage; but further investigation in the field in both California and Idaho make it probable that that they contain also a Brahmanic fauna.

In the upper part of the Werfen beds of the Mediterranean region is found the equivalent of the Jakutic stage, but the fauna is entirely distinct, the most characteristic forms being *Tirolites cassianus*, *Dinarites dalmatianus*, *Aspidites eurasiaticus*, and *Meekoceras ? caprilente*. This species has recently been described by A. Bittner (2) from Darwas in Bokhara, in Central Asia; it therefore seems possible that in Jakutic time a connection began to be established between the Mediterranean and the Oriental regions.

Characteristic genera of the Jakutic stage are *Danubites*, *Ceratites*, *Dinarites*, *Tirolites*, *Sibirites*, *Hedenstrœmia*, *Lecanites*, *Aspidites*, *Meekoceras*, *Proptychites*, *Flemingites*, and *Prosphingites*. Of these, *Lecanites* and *Flemingites* are not found in the Arctic-Pacific region at all. *Hedenstrœmia mojsisovicsi* Diener and *Ceratites subrobustus* Mojsisovics are common to the Indian and the northern Siberian provinces.

During Brahmanic time there was a very intimate connection of the Himalayan and Salt Range provinces of the

Oriental region with the eastern Siberian province of the Arctic-Pacific region, and the American region. This is shown by the community of species between the Asiatic provinces, and the close relationships of many forms on opposite sides of the Pacific Ocean. But the American region has many genera that occur in one or the other of the Asiatic regions, but are not known in both. *Pseudosageceras* and *Ussuria* are not uncommon in the *Meekoceras* beds of California and Idaho, and are known elsewhere only in the *Proptychites* beds of Ussuri Bay. *Lecanites* and *Flemingites* are common to the American and the Oriental regions, but are unknown in the Arctic-Pacific. Thus during Brahmanic time the two regions in Asia seem to have not been directly connected, but rather to have mingled their faunas through some outside sea, with which the American waters were also connected.

In Jakutic time the connection between northern and southern Asia became more intimate, and we find two species identical in the two regions, *Ceratites subrobustus* and *Hedenstrœmia mojsisovicsi*, and many others closely related. And during this expansion of the Asiatic waters two Mediterrean species, *Meekoceras ? caprilente*, and *Aspidites eurasiaticus* made their way into central Asia, although the occurrence of a few doubtful species in the two regions can not offset the fact that the most characteristic genera of the two are wholly different.[1] The faunas of the Scythic series have been described by the following writers: Arctic-Pacific region, E. von Mojsisovics (20 and 25) and Carl Diener (5); in the Oriental region, by W. Waagen (38) from the Salt Range, and from the Himalayas by Carl Diener (3); in the American region, from the Aspen Mountains of Idaho by C. A. White (40), and from the Inyo Range of California by J. P. Smith (33).

The Scythic faunas of the Mediterranean region are described by E. von Mojsisovics in his monograph, "Die Cephalopoden der Mediterranen Triasprovinz" (21).

[1]Dr. A. von Krafft, "Stratigraphic Notes on the Mesozoic Rocks of Spiti" (1900), says that *Ceratites subrobustus* does not occur in the Himalayas in the beds called by Dr. Diener "The Subrobustus beds," but in the next higher group, "Sibirites prahlada beds," so-called base of the Muschelkalk.

THE MIDDLE TRIAS OR DINARIC SERIES.

The Dinaric series is the equivalent of the Alpine and German Muschelkalk, and for this division of the Trias the Mediterranean region furnishes the world's type, and the subdivisions, Lower, Middle, and Upper Muschelkalk, are used wherever deposits of Middle Triassic age are identified. It does not follow that breaks in the series will occur at the same horizon in different regions, and in fact they do not.

Waagen and Diener (27) proposed to divide the Dinaric series, or Muschelkalk, into two stages, a lower or Hydaspic, known only in the upper Ceratite limestone of the Salt Range; and an upper, or Anisic, most characteristically developed in the Alpine province. But Dr. A. Tornquist (35 and 36) has shown that the Fassanic beds, Buchenstein and Marmolata formations of the southern Alps, contain *Ceratites nodosus* and other characteristic species of the Upper Muschelkalk of the Germanic Trias, and must therefore be classed in the Dinaric series. In all probability, then, the Hydaspic stage becomes merely the equivalent of the Lower Muschelkalk. During this stage the connection between the Mediterranean and the Asiatic regions does not seem to have been intimate, for the faunas are entirely distinct. But at this time the genus *Dinarites*, which abounded already in the Lower Trias in the Mediterranean and Arctic-Pacific regions, appeared for the first time in the Salt Range province. Also the genera *Acrochordiceras* and *Hungarites* made their entrance into the Arctic-Pacific and the American regions, while they existed in the Oriental and Mediterranean regions in the Lower Trias. *Tirolites*, *Ptychites*, *Balatonites*, and *Parapopanoceras* appear for the first time in the American region.

In the middle Muschelkalk a closer relation was established between the European and the Asiatic faunal regions, and a few species are common to these. The zone of *Ptychites rugifer* may be taken as interregional, and a basis of comparison of the separated faunas, for a somewhat

similar fauna is found in this horizon in the Mediterranean and the Oriental regions. Correlative beds with somewhat kindred faunas are found in northern Siberia, Spitzbergen, and Nevada, indicating a closer relationship between the Arctic-Pacific and the American regions. The occurrence of *Balatonites* in the Alpine province and in Nevada, while it was lacking in the Oriental and the Arctic-Pacific regions, deserves especial notice.

In the upper Muschelkalk, or Fassanic substage, the equivalents of the Marmolata and Buchenstein formations of the Alps, there was a widespread readjustment, and consequent migration of species into basins or seas previously cut off. This shows itself in the migration of the *Ceratites nodosus* fauna from the Germanic into the Alpine province; further in the appearance of the *Protrachycerata* in the Arctic-Pacific and the American regions, probably as immigrants from the Mediterranean waters, for in the Rikusen beds of Japan, and the lower limestones of the West Humboldt Range of Nevada, is found a fauna closely allied to the Buchenstein fauna of the Alps. Marine fossils of this age are known in the Oriental region, in the lower part of the *Daonella* beds of the Himalayas.

The most characteristic genera of the Muschelkalk are *Ceratites*, *Ptychites*, *Hungarites*, *Beyrichites*, *Balatonites*, *Acrochordiceras*, *Monophyllites;* and for the upper part, *Anolcites*, *Protrachyceras*, *Ceratites*, and *Arcestes*.

The cephalopod faunas of the Muschelkalk have been described by the following authors:

1. *Mediterranean region*, E. von Mojsisovics (21) for the entire region, especially the Alpine province; E. Philippi (29*a*) for the Germanic province; G. von Arthaber (1 and 1*a*) for the Alpine province; F. von Hauer (10 and 11) for the Balkan province, especially Bosnia; A. Tornquist (35 and 36) for the zone of *Ceratites nodosus* in the Alpine and the Germanic provinces; F. Toula (37) for the Byzantine province.

2. *Arctic-Pacific region*, E. von Mojsisovics (20 and 26) for the northern Siberian and the Japanese provinces; C. Diener (5) for the eastern Siberian province.

3. *Oriental region*, W. Waagen (38) for the Salt Range province; C. Diener (4) for the Himalayan province.

4. *American region*, W. M. Gabb, in the Geological Survey of California (9), in which a few species from the Middle Trias of the Humboldt Mountains of Nevada are described; F. B. Meek (18) for the same province, based on a much more complete collection of fossils.

THE UPPER TRIAS.

E. von Mojsisovics divides the Upper Trias into two series, the Tirolic and the Bajuvaric; but there seems to be little use in thus subdividing the old group, Keuper, which ought to stand on the same basis as the Muschelkalk as a unit in comparative stratigraphy.

The Tirolic Series. The Tirolic series has been divided into two stages, the Ladinic (or Noric according to Mojsisovics) and the Karnic. The lower part of the Ladinic, or the Fassanic substage, has recently been shown to belong to the Muschelkalk. The upper Ladinic, or Longobardic substage, unquestionably belongs to the Upper Trias. This is represented in the Mediterranean region by the Wengen beds. A part of the Rikusen beds of Japan may belong here, as also the upper part of the Star Peak limestone of the Humboldt Mountains of Nevada. The Triassic beds of western Canada have been referred to this horizon with somewhat more probability. Marine faunas of Longobardic age are also known in the middle *Daonella* beds of the Oriental region.

The Cordevolic substage of the Karnic, equivalent to the Alpine St. Cassian formation, has been cited from Nevada and California, but it is doubtful if it is represented there. It is certain that the faunas of the West Humboldt Range in Nevada do not belong to the St. Cassian formation, while the beds below the *Halobia* slates in Shasta County, California, may. But in the Californian section the Julic and Tuvalic substages of the Karnic are well represented, with a rich fauna of *Trachycerata* and Tropit-

idæ. The *Trachyceras* beds of British Columbia may also belong here.

The Karnic stage is best represented in the Tyrolian Alps, of which the section is taken as the standard for the rest of the world, and from which the names of the subdivisions are taken. The St. Cassian, the Raibl, and the Sandling beds have long been classic localities for students of geology; their faunas have been described in comprehensive monographs, and are accessible for study in many museums. But the sequence of beds in the Tyrolian Alps is still a matter for discussion, hardly any two writers agreeing as to the exact position of any two beds. And this has made it very difficult for extra-European stratigraphers to avoid serious blunders in comparing individual beds with their supposed equivalents in the Alpine section. The writer had been at work on the Californian section nearly two years before it was published that Mojsisovics had given up his Juvavic and Mediterranean Triassic provinces, and that part of the Hallstatt section was upside down. It was therefore a perplexing thing to find in California an intermingling of Juvavic and Mediterranean types, and also to find the faunas in inverted order as compared with the Alps. But the recent revisions carried out by Mojsisovics, Bittner, G. von Arthaber, and Tornquist in the Tyrolian province have thrown much light on the problems and have given a section that will in most cases stand the test of further work.

The Karnic stage is known with marine cephalopod faunas in the upper *Daonella* beds and the *Tropites* limestone of the Himalayas. Not many species are known, and those poorly preserved, but enough to show that the same types that abounded in the Alps and in California at this time also occurred in India. In India as in California this stage is characterized by the occurrence together in the same rocks of *Trachyceras* and *Tropites*, while in the Alps the *Trachyceras* zone lies below that of *Tropites* and the two are never intermingled. Another peculiarity is that in California there are many species identical with those in

the Alps, and few with those in India, although it would be expected that the Indian province had been the connection between the American and the Mediterranean regions. It seems probable, however, that a complete study of the Spiti section will reveal the presence of a number of species identical with those of America, for Dr. A. von Krafft (15) has published a preliminary list of the fossils of the *Daonella* beds, showing the presence of many that are at least nearly akin to forms in California.

A most remarkable fact is the occurrence of the *Subbullatus* fauna in the Alps, Himalayas, and California, with nearly related species, in the Karnic stage. This fauna appears unheralded by local ancestors, as immigrants from some outside region which at present is unknown. The *Trachycerata* of this fauna seem to have been endemic in the Mediterranean region, but the Tropitidæ are not known in the Muschelkalk anywhere. The two groups did not therefore come from the same region, nor are their relative ages constant over the world. In the Alps the Tropitidæ did not arrive on the scene before the *Trachycerata* had disappeared; in the Himalayas one species of *Trachyceras* has been found in the *Tropites* beds; while in California both *Trachycerata* and Tropitidæ are abundant in the same beds and even in the same hand specimens. It is therefore quite likely that this fauna appeared somewhat earlier in California, and that there the *Tropites subbullatus* beds are the chronologic equivalents of the *Trachyceras aonoides* zone of the Alps, while they are paleontologically homotaxial with the upper Karnic zone.

The Bajuvaric Series. The upper Hallstatt beds are the type of the Bajuvaric series; in them is found a rich assemblage of cephalopods described by Mojsisovics as the Juvavic fauna, but this name has been replaced by the term Noric, which had been previously used for the upper Dachstein strata at a time when they were supposed to lie below the *Tropites subbullatus* beds. A similar group of species, and in the same position, is known in the Himalayas above the *Tropites* beds of

Spiti. In California the upper part of the Hosselkus limestone and the shales above them contain certain genera that seem to be confined to the Noric horizon, especially *Halorites*, *Rhabdoceras*, and *Pseudomonotis subcircularis*, the American representative of the Arctic-Pacific *Pseudomonotis ochotica*, which is found in Siberia, Alaska, Peru, and the Indian Archipelago.

The Rhaetic, or upper division of the Bajuvaric, is not represented by interregional faunas, and its marine equivalents have not been identified outside the Mediterranean region.

Marine faunas of Upper Triassic age have been described in monographic form from the Mediterranean region by E. von Mojsisovics (21–23); from the Arctic-Pacific region by the same author (20); from the Oriental region also by Mojsisovics (24), and by A. von Krafft (15), who has given preliminary lists of species of which descriptions are promised at an early date; from the American region by W. M. Gabb (9), by A. Hyatt (13) in the form of preliminary lists, and by J. P. Smith (31); and from the Canadian province by J. F. Whiteaves (42). The reptilian fauna of the American Trias has been described by Dr. J. C. Merriam (19*a*).

THE TRIAS OF NORTH AMERICA.

Historical. Triassic fossils were discovered in California and Nevada by the State Geological Survey under J. D. Whitney; these were thought by W. M. Gabb (9), the paleontologist of the survey, to be nearly related to the Upper Triassic fauna of the Alps, and certain species were even looked upon as identical with European forms. This was the first discovery of marine Trias in the western hemisphere, and the third discovery outside of Europe, the first being that in northern Siberia by Keyserling (14); the second, that by R. Strachey (34) in the Himalayas of India, and later described by Salter (30). Nothing more was done with the Trias in America until the Survey of the

Fortieth Parallel studied it in the Humboldt Mountains of Nevada, where Meek (18) thought he recognized some Californian species. Shortly after this time Lower Trias was discovered in southeastern Idaho, by the Hayden Survey, and described by Dr. C. A. White (40).

The next publication on the American Trias was by E. von Mojsisovics in "Arktische Triasfaunen" (20), in which some of the species described by Gabb, Meek, and White were compared with ammonites from Siberia, and the relations of the American faunas to those of the Arctic-Pacific region were discussed.

Professor Alpheus Hyatt (13) next undertook a revision of Gabb's work, visiting the original locality in Plumas County, California, adding largely to the faunal list, and especially to our knowledge of the stratigraphic distribution of the species.

In 1892 the writer's attention was called by Dr. H. W. Fairbanks to a bed of ammonite-bearing limestone discovered by him on Squaw Creek near Pitt River in Shasta County, California; on examination, these fossils proved to be of Upper Triassic age. This locality was soon afterwards visited by the writer, who spent the field-season of 1893 at work in that region, and in studying the section in Plumas County. This work brought to light a rich cephalopod fauna, chiefly of Karnic age, and nearly related to characteristic species of the Tyrolian Alps. The writer has since spent a part of the field-seasons of 1895, 1898, 1901, and 1903 collecting in the Shasta region, and has had several collections made there by others; these later collections have added greatly to the lists of fossils, and have necessitated a revision of all the preliminary lists. A part of the results of this work has already been published by the writer (31–33).

One of the most suggestive papers on American Triassic stratigraphy is a chapter entitled "Die Meere der Trias Periode," by Dr. E. von Mojsisovics (24), who on the basis of the existing literature, communications of Professor Hyatt and the writer, and a suite of fossils sent him by the

writer, compares at considerable length the American with the European faunas.

In 1896 Dr. C. D. Walcott discovered some ammonite-bearing limestones in Inyo County, California, on the Union Wash, east side of Owen's Valley, about three miles up from the mill of the Reward Mine. These fossils were submitted to the writer for identification, and proved to be of Lower Triassic age. They were not in good condition for the identification or description of species, but it was possible to identify a number of genera that are characteristic of the Ceratite formation, Lower Trias, of the Oriental region. A preliminary report on this discovery was published by the writer (33). Since that time Mr. H. W. Turner, of the United States Geological Survey, has visited this locality, adding to the collections, and discovering a second ammonite bed about eight hundred feet above the first, with a different fauna, thought by the writer to belong to the lower Muschelkalk. During the winter of 1900-1901, and in 1903, the writer visited this locality, and with the assistance of Messrs. T. J. Hoover and A. M. Strong, made extensive collections from both horizons, including a number of new genera and many old ones never before found in America.

Recently Mr. W. Lindgren (16) has discovered in southeastern Oregon fossiliferous Triassic limestone, but the fossils have not yet been identified.

Mr. R. S. Spence has recently discovered a new locality for Lower Triassic ammonites, one mile west of Paris in southeastern Idaho. The beds contained among other fossils, *Meekoceras*, *Ophiceras*, *Celtites*, and *Pseudosageceras*.

The writer has now visited in person all the Triassic provinces of the United States and has collected at all the principal localities in each province. Therefore his statements as to the occurrence of genera or species in this region are based on personal observation, and on collections made by himself. In addition to collecting at all the principal localities for Triassic fossils, he has studied the

Whitney collection, and the collection of the United States National Museum, embracing the collections made by the Hayden Survey in southeastern Idaho, and by the Survey of the Fortieth Parallel in Nevada. He has also studied all the private collections where Triassic fossils were to be found. A part of the results of this work will shortly appear in a paper by Alpheus Hyatt and James Perrin Smith, "The Triassic Cephalopod Genera of America," to be published in the Professional Papers of the United States Geological Survey. In this work every genus of cephalopods known to occur in the Trias of America is described, and a representative species under each is described and figured.

Geography of the Trias in America. During Triassic time the sea, which had covered the greater part of the Mississippi Valley and the Great Basin in the Upper Carboniferous, had retreated westward until it was reduced to a mere gulf, of which the approximate outlines are shown on plate xl. It is not likely that the sea covered all the area indicated on this map during the whole of the Trias, nor at any one time. Sediments with marine fossils of the Lower Trias are known on the North American continent only in eastern California and southeastern Idaho; marine fossils of the Middle Trias are known only in California and central Nevada; while Upper Triassic marine fossils are known only in northern California, central Nevada, western British Columbia, on Queen Charlotte and Vancouver islands, and on the shores of Alaska.

During the Lower Trias the gulf extended as far eastward as the Aspen Mountains of Idaho; during the Middle Trias it retreated westward until its eastern border was in central Nevada; and at the end of the Trias the land had encroached still further until the gulf was little more than a bay in northern California, and central Nevada, with similar bays in western British Columbia.

Around this western gulf extended the inlets and continental basins in which were deposited the Triassic

Red Beds. These extend in a fringe around the marine sediments from the Grand Cañon region on the south, along the Rocky Mountains, up into British Columbia.

As the sea retreated westward the brackish water basins followed it; thus the Triassic Red Beds do not all belong to one horizon, but take a successively higher place in the column towards the west. In Oklahoma the Red Beds contain Permian fossils of brackish water origin; in northwestern Texas they contain fresh water Triassic fossils. In southeastern Idaho the marine sediments of Lower Triassic age are overlain by barren red sandstones representing the Middle Trias. And in northern California, after the Hosselkus limestone epoch, a series of sandstones were deposited, containing only fossil plants of Rhaetic age. Further than this the encroachment did not go, for in central Nevada and northern California the next epoch, the Lias, is characterized by a marine fauna.

A very similar epicontinental sea has been traced out by W. N. Logan (17) for the Middle Jura, showing a subsidence and transgression of the interior sea over part of the area covered during the Lower Trias.

That these Triassic sediments were laid down in an arm of the greater ocean, and not in a closed basin analogous to the Caspian Sea of to-day, is shown by the fact that their successive faunas show a close relation to forms that existed contemporaneously in other regions bordering on the Pacific Ocean, and in the ancient Mediterranean Sea, or Tethys, which in Mesozoic time covered a large part of southern Asia.

Near the close of the Trias we see the culmination of that progressive elevation of the land that began in the Mississippi Valley region at the beginning of the Coal Measures, and extended gradually across the American continent until all that was left of the great interior sea was merely a small gulf, a few hundred miles in extent. This adds another chapter to the remarkably uniform history of North America which has been recorded in the rhythmical advance and retreat of the sea across its surface

from the Cambrian to the Tertiary. Each period of subsidence, local or wide-spread, has been followed by a period of elevation in which the continent resumed approximately its former shape and extent. Whatever may have been the development of the other continents, North America has been a unit since its history began to be recorded in the Pre-Cambrian sediments laid down in the first sea that covered its surface.

THE LOWER TRIAS.

The Lower Trias of Idaho. Many years ago Dr. A. C. Peale discovered in southeastern Idaho and southwestern Wyoming a series of fossiliferous beds lying below the Red Beds and above the Carboniferous limestone. The fossils found in this formation were described by Dr. C. A. White (40), and assigned to the Lower Trias. Cephalopods were found at but two places: Locality No. 1, in southeastern Idaho, sixty-five miles north of Utah, eighteen miles west of Wyoming, and five miles west of John Gray's Lake; locality No. 2, fifteen miles east of south from locality No. 1.

The section at locality No. 1, according to Dr. C. A. White, is as follows:

A.	(Uppermost beds). Limestones and shales, with *Terebratula semisimplex* White, *T. angustata* Hall, *Aviculopecten idahoensis* Meek	1000 ft. (A–B)
B.	Limestones, with *Eumicrotis curta*, and *Aviculopecten idahoensis* Meek	
C.	Greenish and reddish shales and sandstones, with *Aviculopecten pealei* White	850 ft.
D.	Bluish gray limestones, fossiliferous near the base, with *Meekoceras gracilitatis* White, *M. mushbachanum* White, *Arcestes ? cirratus* White	700 ft.
E.	Reddish and greenish sandstones	400 ft.
F.	Dark blue sandstone	800 ft. (F–G)
G.	Quartzite	
H.	Massive gray limestone	400 ft.

At locality No. 2 were found *Meekoceras gracilitatis* White and *M. aplanatum* White, in limestone similar to that marked

D in locality No. 1, and this part of the section unquestionably belongs to the Lower Trias, although it is not likely that the entire thickness of beds there is referable to this division. In a later paper Dr. C. A. White (41) expressed the opinion that the *Meekoceras* fauna of Idaho ought possibly to be placed in the Permian rather than in the Trias, because of the conformity with the Carboniferous beds below, and because of the presence in the fauna of certain Carboniferous elements. These were precisely the arguments used ten years later by F. Noetling for placing the Lower Triassic faunas of India in the Permian, but there is just as little ground for this in the one region as in the other. This question has been fully discussed by the writer (33*a*) in a recent paper.

In 1888 Professor Alpheus Hyatt discovered a third locality for Lower Triassic ammonites in southeastern Idaho, in the Aspen Mountains, in Wood Cañon, about nine miles east of Soda Springs. In 1900 and 1903 the writer visited this same locality, which lies only a few miles southwest of locality No. 2 of White. The joint collections of Professor Hyatt and the writer yielded the following ammonites:[1] *Danubites whiteanus* Waagen, *Danubites* sp. nov., *Meekoceras gracilitatis* White, *Meekoceras* three new species (of which one may be identical with *M. boreale* Diener), *M. (Koninckites) mushbachanum* White, *M. (Gyronites) aplanatum* White, and two other species of the same subgenus, *Aspidites* sp. nov., *Flemingites* sp. nov., *Ophiceras* sp. nov., *Hedenstrœmia* sp. nov., *Clypites* sp. nov., *Ussuria* two new species, and *Nannites* sp. nov. Besides those here listed there were found several new genera of the same families.

This fauna is intimately related to the Lower Triassic faunas of India and eastern Siberia, with several species that may even be identical with those from Asia. It contains several genera hitherto known only from the Lower Trias of India, and others previously found only in the *Propty-*

[1] The new genera and species of this fauna will be described in the publications of the United States Geological Survey.

chites beds of Ussuri Bay in Siberia; it is therfore referred with certainty to the Brahmanic stage of the Scythic series. It may be correlated with the Ceratite marls and the lower part of the Ceratite sandstone of the Salt Range of India.

Mr. R. S. Spence has recently collected some Lower Triassic ammonites at a newly discovered locality one mile west of Paris, in southeastern Idaho. These were sent by the United States Geological Survey to the writer for identification, and proved to be *Meekoceras*, *Ophiceras*, *Pseudosageceras*, *Celtites*, and several species of a new genus of the Sibiritidæ.

The Lower Trias of California. In 1896 Dr. C. D. Walcott discovered some ammonite-bearing limestones in Inyo County, California, on the east side of Owen's Valley, ten miles east-northeast of Lone Pine, three miles southeast of the Reward Mill, and about fifteen hundred feet up above the mill, on the Union Wash trail from Independence over the Inyo Range into Saline Valley. The fossils were submitted by Dr. Walcott to the writer for identification, and referred to the Lower Trias, on the basis of the occurrence of several genera characteristic of the Brahmanic stage of the Scythic series in the Oriental region. In a preliminary report (33) the writer did not venture to describe new species or genera, but noted the occurrence of *Nannites*, *Clypites ?*, *Koninckites*, *Meekoceras*, *Kingites*, *Gyronites ?*, *Xenaspis*, *Dinarites*, and a new genus of Tropitidæ. Later collections and better material have confirmed most of these identifications, but the form referred to *Clypites* has proved to be a new genus of the same group; the supposed *Kingites* is very uncertain; the *Dinarites* has turned out to be a *Paralecanites;* and the supposed new genus of the Tropitidæ belongs to the Hungaritidæ.

Later collections, by Mr. H. W. Turner of the United States Geological Survey, and by the writer, have added greatly to the list of genera and species, bringing out even more strongly the relations of this fauna to the Brahmanic faunas of the Asiatic regions.

At the base of the section seen on the Union Wash are massive siliceous and calcareous beds supposed, on the basis of fossils found in the float, to belong to the Carboniferous; then several hundred feet of calcareous shales with obscure traces of ammonites; then about fifteen feet of hard gray siliceous limestone, from which all the fossils listed from this horizon were taken. Above this limestone lie about eight hundred feet of dark shales with a few impressions of ammonites; then about five feet of impure earthy black limestone with numerous ammonites, *Ptychites*, *Hungarites*, *Acrochordiceras*, *Xenodiscus*, thought by the writer to belong to the base of the Middle Trias, or the *Subrobustus* beds of the Oriental region. These latter will therefore be treated under the Middle Trias.

The fauna collected from the gray limestone by Dr. C. D. Walcott, Mr. H. W. Turner, and the writer yielded the following species: *Sibirites ?* sp. nov., *Danubites* two new species, *Lecanites* sp. nov., *Meekoceras gracilitatis* White, *M.* conf. *falcatum* Waagen, *M.* conf. *radiosum* Waagen, *M. (Koninckites) mushbachanum* White, *M. (Koninckites ?)* conf. *radiatum* Waagen, *M. (Gyronites) aplanatum* White, and six new species of *Meekoceras*, *Prionolobus* sp. nov., *Aspidites* two new species, *Proptychites* sp. nov., *Xenaspis* two new species, *Ophiceras* conf. *sakuntala* Diener, and three new species of this genus, *Nannites* sp. nov., *Pseudosageceras* sp. nov., *Clypites ?* sp. nov., *Ussuria* sp. nov., and *Prosphingites* sp. nov. In addition to these were found also several new genera allied to the Pinacoceratidæ.

This fauna shows a considerable number of characteristic species identical with forms from the *Meekoceras* beds of the Aspen Mountains in Idaho, and a number possibly identical with species from the Lower Triassic Ceratite formation of the Asiatic regions; it is therefore referred with certainty to the Brahmanic stage of the Scythic series, or more exactly, to the equivalents of the Ceratite marls and the lower part of the Ceratite sandstone of the Salt Range of India.

In the Lower Trias, *Meekoceras* beds, of the Asr
tains of Idaho and the Inyo Range of Californ

the following genera hitherto known only from the Ceratite formation of India, *Flemingites*, *Aspidites*, *Prionolobus*, *Clypites;* the following genera have been found hitherto only in the Lower Trias of Siberia, *Pseudosageceras*, *Ussuria;* the following genera have been found heretofore only in the Lower Trias of the Indian and Siberian provinces, *Proptychites*, *Xenaspis*, *Ophiceras*, *Hedenstrœmia*, and *Prosphingites*.

It is plain that the American region contains, along with its endemic elements, a mixture of genera from the two Asiatic regions, which were probably no more intimately connected with each other, than with the American region. The Siberian, the Indian, and the American provinces all opened out into the greater Pacific Ocean, and along the margins of these waters took place the migrations that caused this intermingling of the faunas. But no connection existed with the Mediterranean region during the Brahmanic stage of the Lower Trias.

Dr. H. W. Fairbanks has discovered in the Santa Ana Range, Orange County, California, some fossiliferous limestones with pelecypods resembling *Daonella* and a trachyostracan ammonite not generically identifiable. These beds probably represent the Lower Trias, but the fossils are too scanty for a definite opinion to be based on them.

THE MIDDLE TRIAS.

The Muschelkalk of Nevada. The Geological Survey of California under J. D. Whitney discovered in the Humboldt Mountains of Nevada some fossiliferous limestone containing ammonites referred by W. M. Gabb (9) to the Upper Trias, and correlated with the St. Cassian formation of the Alps. Most of the species were obtained in the cañons on the eastern flanks of the West Humboldt Range, although the data given by Gabb concerning the fossiliferous strata are meager.

About ten years later the Geological Exploration of the Fortieth Parallel brought to light a considerable number of

new species and genera from the Humboldt Range; these were described by F. B. Meek (18) and referred to the St. Cassian formation of the Upper Trias, although Professor Alpheus Hyatt, who also examined all the collections, always adhered to the opinion that the fauna belonged to the Middle Trias, or Muschelkalk. The most characteristic genera obtained by the two surveys were *Orthoceras, Arcestes, Protrachyceras, Ceratites, Danubites, Eutomoceras, Sageceras, Eudiscoceras,* and *Daonella*, an association sufficient to stamp these beds as either Muschelkalk or the lower part of the Upper Trias.

The general section of the Trias in the West Humboldt Range, as determined by the Geological Exploration of the Fortieth Parallel is as follows:

6. Quartzite	2200 ft.
5. Limestone . . . . . probably	1000 ft.
4. Thinly bedded quartzite	1000 ft.
3. Ferruginous limestones	2000 ft.
2. Slaty quartzite	1500 ft.
1. Argillaceous limestone, full of fossils	1500 ft.
Metamorphic Koipato group, unfossiliferous	6000 ft.

All the Triassic fossils from the Humboldt region described by the Geological Survey of the Fortieth Parallel, came from limestone No. 1, although probably several different horizons are represented in this series. Most of the fossils, however, were taken from the base of the formation.

W. M. Gabb (9) cites "*Ammonites ramsaueri*," *Ammonites homfrayi*, and *Pseudomonotis subcircularis* Gabb from the Humboldt region; all these species are characteristic of the Upper Trias of California. It therefore seems certain that the Upper Trias is represented in the upper limestones of the Humboldt Range.

In 1888 Professor Alpheus Hyatt visited the West Humboldt Range and made collections from the *Daonella* beds. These, together with the original Whitney collections and those of the Survey of the Fortieth Parallel, were placed at the writer's disposal for study, and much undescribed

material was found in them, sufficient to make certain the Muschelkalk age of at least part of the series.

The following is a preliminary list of the cephalopods of the Middle Triassic found in these collections from the *Daonella* beds of the Humboldt region:

ARCESTIDÆ, *Joannites gabbi* Meek, *Joannites* sp. nov.
LYTOCERATIDÆ, *Monophyllites billingsianus* Gabb
MEEKOCERATIDÆ, *Beyrichites rotelliformis* Meek, *Lecanites* sp. nov.
HUNGARITIDÆ, *Hungarites* sp. nov.
PTYCHITIDÆ, *Ptychites* sp. nov., *P.? perplanus* Meek
PINACOCERATIDÆ, *Sageceras gabbi* Mojsisovics
CELTITIDÆ, *Celtites halli* Mojsisovics
TROPITIDÆ, *Eutomoceras laubei* Meek
CERATITIDÆ, *Acrochordiceras hyatti* Meek, *Balatonites* two new species, *Anolcites meeki* Mojsisovics, *A. whitneyi* Gabb, *Protrachyceras americanum* Mojsisovics, *P. subasperum* Meek, *Eudiscoceras gabbi* Meek, *Japonites?* sp. indet., *Ceratites blakei* Gabb, *C. meeki* Mojsisovics, *C. nevadanus* Mojsisovics
NAUTILOIDEA, *Orthoceras blakei* Gabb, *Nautilus multicameratus* Gabb, *Nautilus whitneyi* Gabb

In addition to the above, Meek has described from this formation as *Halobia lommeli*, a species very closely allied to *Daonella lommeli* Wissmann, of the Wengen beds, base of the Alpine Upper Trias.

In several publications Dr. E. von Mojsisovics (20 and 24) has referred the Star Peak fauna to the lower part of the Upper Trias, correlating them with the Fassanic substage of the Tirolic series, and comparing them more especially with the Ceratite beds of Rikusen, Japan, and the Buchenstein beds of the Alps. But Dr. A. Tornquist (35 and 36) has shown that Ceratites of the group of *Ceratites nodosus*, a group diagnostic of the upper Muschelkalk of the Germanic basin, are found in the Buchenstein beds of the southern Alps, and that this formation must also be classed with the Muschelkalk. This makes it necessary to refer the Ceratite beds of Japan and their equivalents in Nevada to the Middle Trias. Even without this evidence, the occurrence of *Ptychites*, *Hungarites*, *Beyrichites*, *Acrochordiceras*, *Ceratites*, and *Balatonites* would be enough to make the reference certain, as none of these genera in their typical forms occur higher up than the Muschelkalk.

Many of the commonest species in the Middle Trias of the West Humboldt Range appear to be most closely related to forms in the zone of *Ceratites trinodosus* of the Mediterranean region, as *Ceratites* conf. *trinodosus* Mojsisovics, *Ceratites* conf. *planus* Arthaber, and *Ceratites* conf. *altecostatus* Arthaber.

It is therefore likely that not only the lower Ladinic, but also the upper Anisic stage is represented in the *Daonella* beds of Nevada.

The writer has recently (May 1902 and July 1903) visited the West Humboldt Range in the study of Triassic stratigraphy, and has made extensive collections, especially in the Middle Trias.

The fossils of the Middle Trias were all found in limestone No. 1 of the Survey of the Fortieth Parallel; the fossiliferous beds are not more than two hundred feet thick, and lie near the base of this division.

In Buena Vista Cañon, near Unionville, were found:

Gymnotoceras blakei Gabb
Beyrichites rotelliformis Meek
Acrochordiceras hyatti Meek
Ptychites? perplanus Meek
Dinarites sp. nov.
Balatonites sp. nov.

In Cottonwood Cañon, near the "Lucky Dog" Mine, were found:

Daonella dubia Gabb
Daonella aff. *lommeli* Wissmann
Orthoceras blakei Gabb
Eudiscoceras gabbi Meek
Anolcites meeki Mojsisovics
Anolcites whitneyi Gabb
Gymnotoceras blakei Gabb
Ceratites conf. *trinodosus* Mojsisovics
Longobardites sp. nov.
Acrochordiceras hyatti Meek
Beyrichites rotelliformis Meek
Ptychites? perplanus Meek
Arcestes gabbi Meek
Atractites sp. nov.
Celtites halli Mojsisovics
Japonites sp. indet.
Encrinus stems

Saurian bones and teeth, probably referable to *Cymbospondylus* Leidy.

A new locality was found by the writer on the divide between the south fork of American Cañon and Troy Cañon, four miles south of Foltz Post-Office. At this locality

Middle Triassic fossils are more abundant and better preserved than anywhere else in the Humboldt region. The beds lie in a saddle between two small peaks, at about five thousand feet above sea level, about one mile west of the mouth of Troy Cañon. The shaly limestones are literally full of fossils, and the rock is so soft that they can easily be separated from the matrix. The geologic horizon seems to be the same as that in Cottonwood and Buena Vista cañons, for most of the species are the same as those found at these localities, but there is sufficient difference in the faunas to suggest a slight difference in age.

The writer found at this locality:

Daonella dubia Gabb
Daonella conf. *lommeli* Wissmann
Orthoceras blakei Gabb
Anolcites meeki Mojsisovics
Anolcites whitneyi Gabb
Ceratites conf. *trinodosus* Mojsisovics
Ceratites conf. *planus* Arthaber
Ceratites vogdesi Smith
Ceratites nevadanus Mojsisovics
Ceratites (several new species)
Hungarites sp. nov.
Longobardites sp. nov.
Beyrichites rotelliformis Meek
Beyrichites sp. nov.
Arcestes gabbi Meek
Eutomoceras laubei Meek
Eutomoceras dunni Smith
Sageceras gabbi Mojsisovics
Celtites halli Mojsisovics
Celtites sp. nov.
Dinarites sp. indet.
Danubites sp. indet.
Acrochordiceras aff. *hyatti* Meek
Ptychites? perplanus Meek
Gymnotoceras blakei Gabb
Gymnotoceras meeki Mojsisovics
Gymnotoceras (several new species)
Atractites sp. indet. (very abundant)

Saurian bones, probably of *Cymbospondylus* Leidy.

Of this fauna *Eutomoceras laubei* and *Sageceras gabbi* have been referred to by Mojsisovics[1] as probably occurring in the higher part of the Trias, but the writer found them in the same bed with the others. The list of fossils given above can only mean that the beds belong to the Middle Trias, and possibly not merely to the uppermost zone of that formation, but in part also to the zone of *Ceratites trinodosus*.

The Middle Trias of California. The upper limestone of the Union Wash, west side of the Inyo Range, and about three miles up above the Reward Mill has been

[1] Cephal. Ob. Trias d. Himalaya, p. 696.

referred by the writer somewhat doubtfully to the lower Muschelkalk. It lies about eight hundred feet above the Ceratite limestone with the typical Lower Triassic fossils, and is apparently conformable with that series. Mr. H. W. Turner, the discoverer of the beds, made collections there in 1899; and in 1900 and 1903 the writer visited the locality, adding a number of other species to the list. The cephalopods obtained by the joint collections were the following:

ARCESTIDÆ, *Parapopanoceras* sp. nov.
PTYCHITIDÆ, *Ptychites* sp. nov., *Nannites* sp. nov.
HUNGARITIDÆ, *Hungarites* sp. nov.
CELTITIDÆ, *Celtites* sp. indet., *Xenodiscus*, sp. nov.
CERATITIDÆ, *Acrochordiceras* sp. nov., *Tirolites (Metatirolites)* sp. nov., *Ceratites ?* sp. indet.
NAUTILOIDEA, *Orthoceras* sp. nov.

These beds may possibly belong to the Jakutic stage of the Lower Trias, but the occurrence of *Parapopanoceras* and *Ptychites* makes this improbable. Also *Hungarites*, *Acrochordiceras*, and *Tirolites* are wholly lacking in the undoubted Lower Trias of Idaho and California, and their appearance in the American waters marks a later epoch than the Brahmanic. But the character of the fauna is not that of the *Hedenstrœmia* beds of the Asiatic regions, and so they are thought to be homotaxial with the bottom of the Middle Trias, older than any of the Muschelkalk beds known from Nevada. Above them lie about one hundred and fifty feet of shales with *Ceratites?* and *Balatonites?*, resembling forms from the Middle Trias of Nevada.

With these beds the sedimentary Triassic series of the Inyo Range ends, and above them are found sheets of lavas.

Some years ago the writer discovered fossils in the Pitt shales at Silverthorn's Ferry on Pitt River, Shasta County. These fossils were *Anolcites* conf. *whitneyi* Gabb, *Ceratites* sp. nov., and *Arcestes (Joannites)* sp. indet. On the basis of these genera, and their occurrence about fifteen hundred feet below the Upper Triassic limestone of Squaw Creek, these siliceous shales were referred to the Middle Trias, a conclusion still upheld by the writer.

THE UPPER TRIAS.

The Upper Trias of Plumas County, California. The Whitney Geological Survey of California first discovered fossils characteristic of the Upper Trias in some shales near Robinson's Ranch in Genesee Valley on Indian Creek, Plumas County. Only the Upper Trias is represented in the section at that locality, the shales and limestones resting unconformably on the Carboniferous. Only a very few fossils were found there, but *Pseudomonotis subcircularis* Gabb was enough to determine the age of the beds. This along with *Ammonites ramsaueri* Gabb (not Hauer) and a few other molluscs, was described by W. M. Gabb in Vol. I, Palæontology of California, in which also the first description of the Middle Trias of Nevada was published.

Many years later Mr. J. S. Diller and Professor Alpheus Hyatt visited the Trias of Plumas County, and undertook a revision of the work of Gabb. They found numerous fossils in the limestones as well as in the slates, and proved the occurrence in California of a fauna equivalent to the classic Hallstatt fauna of the Alps. The general section of the Trias of Genesee Valley as worked out by Diller (7) and Hyatt (13) is as follows:

1. *Hosselkus limestone*, with *Tropites* conf. *subbullatus*, *Juvavites*, *Badiotites?*, *Arcestes*, *Atractites*, 140 ft.
2. *Halobia slates*, with *Halobia* conf. *superba*, *H.* conf. *rugosa*, *Tropites* conf. *subbullatus*, *Arcestes*, *Atractites*, [about 100 ft.]
3. *Swearinger slates*, 200 ft.
   Rhabdoceras bed, with *Rhabdoceras*, *Atractites*, *Halorites*, *Arcestes*, and numerous pelecypods.
   Daonella bed, with *Daonella*, *Pseudomonotis*, and numerous pelecypods.
   Pseudomonotis bed, with *Pseudomonotis subcircularis*, and other pelecypods.

The Swearinger slates were supposed to underlie the *Halobia* slates, but the strata are much faulted and the sequence obscure. Hyatt (13) states that "above the *Rhabdoceras* bed lie unfossiliferous quartzites, but to the westward, near the top of the Carboniferous spur (so-

called on account of the presence of fossiliferous rocks of that system), we found a bed of slates containing *Halobia*, occurring in banks as did the *Monotis* below on the Triassic spur." It is, however, not likely that the upper series would be represented in one place by unfossiliferous quartzites and a mile or so away by thinly bedded calcareous shales, nor that the *Halobia* slates should rest in one place on the eroded surface of the Carboniferous and in another place a few hundred yards away on a thick series of calcareous shales with Upper Triassic fossils. In fact, the *Halobia* beds seem to be the oldest Trias present in the Genesee Valley, and the Swearinger slates are probably brought down to their position by faulting. *Rhabdoceras* and *Halorites* are uniformly characteristic of higher horizons than the *Tropites subbullatus* fauna in the West Humboldt Range of Nevada, as well as in the Alps. Dr. E. von Mojsisovics (24) has shown in his discussion of the sequence of faunas of the Trias that the *Pseudomonotis* beds belong to the Bajuvaric series, and consequently above the Karnic horizon, to which the *Halobia* slates and the Hosselkus limestone belong. This view is also in accordance with the section described by the writer in Shasta County, California, where the *Pseudomonotis* shales were found above the Hosselkus limestone. In all probability no Trias lower than the Karnic occurs in the Genesee section.

Mr. J. S. Diller (7) has described from the Taylorsville region, under the name of Foreman beds, a series of slates and conglomerates with plant remains, assigned by Professor W. M. Fontaine to the Rhaetic. It seems then that in California the Triassic marine history ended with the *Pseudomonotis* beds, and that during Rhaetic time the land had encroached still further on the sea by the progressive westward uplift.

The Upper Trias of Shasta County, California. In 1892 Dr. H. W. Fairbanks discovered some ammonite-bearing limestones about nine miles northeast of Copper City, Shasta County, on the divide between Squaw Creek and

Pitt River, near the trail from Madison's Ranch to Brock's. These fossils were submitted to the writer for identification, and proved to belong to the *Tropites subbullatus* fauna. The writer afterwards spent part of the field seasons of 1893, 1895, 1898, 1901, and 1903 collecting in that region, and had several collections made for him there by others. The fossils are very abundant and well preserved, and a large quantity of material has been accumulated. Preliminary accounts of the results of these studies have already been published by the writer (31–33), but further studies in the field and museum, and new publications concerning Triassic paleontology and stratigraphy in foreign regions have necessitated much revision of the lists of species.

The general section of the Shasta County Trias, as worked out by the writer, is as follows:

UPPER TRIAS	Noric		*Pseudomonotis* shales, thickness unknown
		Hosselkus limestone	*Spiriferina* beds, 50 ft. hard siliceous limestone *Juvavites* beds, 100 ft. siliceous limestone, with *Juvavites, Tropites, Arcestes*, and *Atractites*
	Karnic		*Trachyceras* beds, 50 ft. soft limestone, with *Trachyceras, Clionites, Sagenites, Arpadites, Polycyclus, Eutomoceras, Tropites subbullatus*, etc. *Halobia* slates, 100 ft. calcareous slates, with *Halobia superba, Tropites, Polycyclus, Protrachyceras*, etc.
	Ladinic		*Protrachyceras homfrayi* beds, 100 ft. calcareous argillites, with *Protrachyceras* conf. *homfrayi, Halobia*, etc.
MIDDLE TRIAS	Muschelkalk	Pitt shales	Siliceous shales and conglomerates, with *Anolcites whitneyi, Ceratites* sp. nov., *Arcestes (Joannites)*, of Silverthorn's Ferry on Pitt River, about 1500 ft. below the fossiliferous limestones. Total thickness probably 2000 or 3000 ft.

Most of the fossils collected in this region were taken from the *Trachyceras* bed, the zone of *Tropites subbullatus*. The following is a list of the most important forms:

TROPITIDÆ

Tropites subbullatus Hauer
Tropites dilleri Smith
Tropites torquillus Mojsisovics
Tropites (many new species of the *Subbullatus* group)
Paratropites sellai Mojsisovics
Paratropites dittmari Mojsisovics
Paratropites (several new species of this group)
Sagenites erinaceus Dittmar
Sagenites herbichi Mojsisovics
Eutomoceras sandlingense Hauer
Juvavites subinterruptus Mojsisovics
Juvavites (Anatomites) sp. nov.
Tropiceltites sp. nov.
Homerites semiglobosus Hauer

CERATITIDÆ

Polycyclus henseli Oppel
Arpadites sp. nov. (group of *A. cinensis*)
Tirolites foliaceus Dittmar
Sirenites sp. nov.
Sandlingites sp. nov.
Trachyceras (Protrachyceras) shastense Smith
(several new species of the group of *T. attila*)

PINACOCERATIDÆ

Hauerites (two new species)
(new genus of this group)

PTYCHITIDÆ

Nannites? sp. nov.
(new genus of this group)

ARCESTIDÆ

Arcestes (Proarcestes) sp. nov.

LYTOCERATIDÆ

Monophyllites (Mojsvarites) sp. nov.

NAUTILOIDEA

Orthoceras sp. nov.
Proclydonautilus triadicus Mojsisovics
(several new species of *Nautilus*)

BELEMNOIDEA

Atractites sp. nov.

PELECYPODA

Halobia superba Mojsisovics

BRACHIOPODA
- *Terebratula* sp. nov.
- *Rhynchonella* sp. nov.

VERTEBRATA
- *Shastasaurus*[1] *alexandræ* Merriam
- *Shastasaurus altispinus* Merriam
- *Shastasaurus careyi* Merriam
- *Shastasaurus osmonti* Merriam
- *Shastasaurus pacificus* Merriam
- *Shastasaurus perrini* Merriam
- *Leptocheirus*[2] *zitteli* Merriam
- *Toretocnemus*[3] *californicus* Merriam

The fauna of the *Juvavites* beds differs from that of the *Trachyceras* beds in the absence of *Trachyceras*, the scarcity of the *Subbullatus* group, and the prevalence of *Juvavites*, *Arcestes*, and *Atractites*.

The fauna of the *Spiriferina* beds consists chiefly of Brachiopoda, with a few pelecypods, corals, and crinoids, hardly determinable. It is probable that the upper part of the *Juvavites* beds and the *Spiriferina* beds belongs to the Noric division of the Bajuvaric series, for the *Pseudomonotis* slates occur just above them in the section between Squaw Creek and Pitt River, and undoubtedly belong to the Noric, or what Mojsisovics formerly called Juvavic.

In a former paper the writer (31) erroneously referred the *Protrachyceras homfrayi* beds to the Swearinger slates of Diller, on account of their stratigraphic position below the *Halobia* slates.

But the fauna of the *Protrachyceras homfrayi* beds is quite different, and probably belongs to the Longobardic substage of the Ladinic. They contain *Protrachyceras homfrayi* Gabb, and several other species of this group, along with a number of poorly preserved pelecypods, including *Halobia*. A further examination of the fauna in the field, and in the collections previously made, failed to show the presence of *Pseudomonotis* in the lower shales, but showed it to be abundant in the shales above the Hosselkus limestone. These shales outcrop between the divide and

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[1] See Bibliog. 19 and 19*a*.
[2] See Bibliog. 19*b*.
[3] See Bibliog. 19*b*.

Brock's Ranch, and the fossils proved to be typical and well-preserved specimens of *Pseudomonotis subcircularis* Gabb. This is sufficient proof that the Californian section of the Upper Trias is in accord with that observed in other parts of the world.

These Triassic limestones and slates extend from Brock's Ranch on Pitt River northward about thirty miles, crossing Squaw Creek west of Kelly's Ranch near the forks of Squaw Creek. They were also found on Bear Mountain, five miles southwest of Silverthorn's Ferry on Pitt River. They are fossiliferous almost everywhere, and are easily traced, because the massive Hosselkus limestone usually caps the ridges. The best collecting ground is about three miles northeast of Madison's Ranch on Squaw Creek, and also about a mile and a half east of Terrup-chetta (Cottonwood Flat) on Squaw Creek, six miles north of Madison's. In order to find the collecting grounds it is only necessary to go along the base of the cliffs until an outcrop of the soft *Trachyceras* limestone is seen, then abundant fossils may be obtained anywhere in this area. The structure is quite simple, the ridges being usually east-dipping monoclines, and the stratigraphic position of each bed may be determined without difficulty.

The Humboldt Range. Our knowledge of the stratigraphy of the beds above the Middle Trias in the Humboldt Range has been until recently exceedingly meager. But W. M. Gabb (9) has cited from there "*Ammonites*" *ramsaueri* Gabb (not Hauer), "*Ammonites*" *homfrayi*, and *Pseudomonotis subcircularis*, all of which have since been shown to be characteristic of the Upper Trias of California, and not to be associated with Middle Triassic faunas. The writer has recently made an extended journey in the West Humboldt Range in Nevada, in the study of the stratigraphy of the Trias. The greater part of the massive limestone of that region seems to belong to the Upper Trias, as the Muschelkalk beds with their characteristic fauna lie at the base of the Star Peak limestone. About eight hundred feet above the uppermost beds of the Middle Trias the

writer found a few scarcely determinable fossils, among them a *Halobia* resembling *H. superba*, which is common in the Karnic beds of Shasta County, California.

Above the Star Peak limestone there is a series of shales and shaly limestones aggregating about eight hundred feet in thickness. These are best exposed in the Muttleberry Mountains, in Muttleberry Cañon, about eight miles southeast of Lovelock, Nevada.[1] At this locality the writer found *Arcestes* sp. nov., *Rhabdoceras russelli* Hyatt, *Placites* sp. indet., *Halorites* sp. indet., and *Pseudomonotis subcircularis*, the last very abundant.

These beds are overlain uncomformably by impure limestones of the Lower Jura, or Lias, with *Arietites (Caloceras)* conf. *nodotianus* d'Orbigny. It is therefore more than a probability that the Star Peak limestone corresponds in part, at least, to the Hosselkus limestone of the Upper Trias of California, and that in both regions the *Pseudomonotis* beds mark the highest horizon of the marine Trias.

The Upper Trias of British Columbia and Alaska. The Geological Survey of Canada has discovered Triassic fossils at a number of localities in western British Columbia, Stikine River, Peace River, Nicola Lake, Liard River, about twenty-five miles below Devil's Portage, lat. 59° 16′ N., long. 125° 35′ W., Vancouver Island, and Queen Charlotte Islands. Most of the fossils known from that region came from the two last localities, and they all seem to belong to the Upper Trias; but it is not likely that they all came from the same horizon, for *Halobia lommeli* belongs to the Longobardic substage, while *Pseudomonotis subcircularis* Gabb belongs to the Noric stage, and both are cited from Queen Charlotte Islands, along with *Acrochordiceras? carlottense* Whiteaves, *Arniotites vancouverensis* Whiteaves, *Badiotites? carlottensis* Whiteaves, *Arcestes gabbi* Meek, and *Aulacoceras carlottense* Whiteaves. From the Liard River locality are listed: *Halobia lommeli* Wissmann, *H. occidentalis* Whiteaves, *Monotis ovalis* Whiteaves, *Trigono-*

[1]The writer is indebted to Mr. Frank M. Anderson of Berkeley, California, for the discovery of this locality.

dus productus Whiteaves, *Margarita triassica* Whiteaves, *Nautilus liardensis* Whiteaves, *Popanoceras macconnelli* Whiteaves, *Trachyceras canadense* Whiteaves, *Spiriferina borealis* Whiteaves.

These species probably represent both Tirolic and Bajuvaric faunas, but the information is at present too meager for one to assign them to anything more definite than the Upper Trias in general. All the information available and figures and descriptions of all these species have been published by Dr. J. F. Whiteaves (42).

But little is known concerning the Trias of Alaska, fossils of that age having been found at but few places. Dr. Paul Fischer (8) has described the occurrence of *Monotis* shales on the shores of the Peninsula of Alaska, but it is quite probable that the forms referred to belong rather to *Pseudomonotis*. Dr. C. W. Hayes (12) discovered in the St. Elias Range some black shales, containing *Pseudomonotis* conf. *subcircularis* Gabb. These occurrences make it reasonably certain that the Upper Trias extended from British Columbia through Alaska into northeastern Siberia, for the *Pseudomonotis* fauna is found in all these regions.

General Discussion and Summary of the American Trias.

The entire Triassic column is now known to be represented in the United States, although only parts of it in any one locality. While the areal distribution of Marine Trias in America is small, the richness of the faunas compares favorably with that of formations that cover the greater part of the surface of the continent.

Marine faunas of Lower Triassic age are now known only in the *Meekoceras* beds of the Aspen Mountains of southeastern Idaho and in the Inyo Range of California, where the faunas are very similar and belong to the Brahmanic and possibly the lower Jakutic stages. The most characteristic genera in these two localities are *Meekoceras*,

Aspidites, *Gyronites*, *Koninckites*, *Lecanites*, *Clypites*, *Proptychites*, *Nannites*, *Hedenstrœmia*, *Pseudosageceras*, *Ussuria*, *Danubites*, *Ophiceras*, and *Flemingites*. This association shows an intimate connection with both the Oriental and the northern Arctic-Pacific regions, and a separation from the Mediterranean waters.

Middle Triassic faunas are known certainly only from California and Nevada, where the beds have been found over a considerable area, representing several horizons of the Muschelkalk. The lowest beds are known only in the Inyo Range of California, characterized by the genera *Acrochordiceras*, *Hungarites*, *Ptychites*, *Tirolites*, *Ceratites ?*, and *Xenodiscus*. The upper horizons of the Muschelkalk are found in Shasta County, California, but are best represented in the West Humboldt Range of Nevada; the most distinctive genera of that region are *Ceratites*, *Beyrichites*, *Danubites*, *Acrochordiceras*, *Anolcites*, *Protrachyceras*, *Balatonites*, *Hungarites*, *Sageceras*, *Ptychites*, *Arcestes (Joannites)*, and *Daonella*.

Hungarites and *Tirolites* are probably immigrants from the Mediterranean region, from which also probably came *Balatonites*, although it is still unknown in the Oriental and the Arctic-Pacific regions. *Acrochordiceras* and *Ceratites* probably reached America from the Asiatic waters, for both had flourished there in the Lower Trias. Thus a connection existed during this time with both the Asiatic and the Mediterranean regions.

Upper Triassic marine faunas are best known in California, in Plumas and Shasta counties, where the most distinctive genera are *Tropites*, *Sagenites*, *Paratropites*, *Eutomoceras*, *Juvavites*, *Polycyclus*, *Trachyceras*, *Clionites*, *Arpadites*, *Arcestes*, *Halobia*, and *Pseudomonotis*. The zone of *Tropites subbullatus* with its characteristic fauna is remarkably like that of the Alps and the Himalayas, with many species identical with forms in the Mediterranean region. But in California the *Trachyceras* and the *Tropites* faunas were synchronous, while in the Alps the *Trachyceras* faunas preceded the zone of *Tropites subbullatus* and are

never found in it. So far as can be judged from our present knowledge, the Upper Triassic faunas of California are more intimately related to the Alpine than to the Himalayan species; but this is probably due to defective information, for the Indian region would seem to have been the most natural and probable connection between the American and the Alpine Trias.

The uppermost marine Trias, the Noric horizon, is represented in the *Pseudomonotis* beds of Shasta and Plumas counties, California, and in the West Humboldt Range of Nevada. The characteristic forms of this stage are *Pseudomonotis subcircularis* Gabb, *Rhabdoceras russelli* Hyatt, *Halorites americanus* Hyatt, *Placites* sp. nov., and *Arcestes* sp. nov.

This same association is characteristic of the Noric of the Mediterranean region.

From the data brought forward in this paper it becomes clear that the stratigraphy of the Triassic system of America is in perfect harmony with that of the typical regions, and that the richness of its faunas will compare favorably with that of any in the world. The writer now has more than three hundred species of cephalopods from the Trias of Western America.

DESCRIPTIONS OF THE SPECIES.

Genus **Meekoceras** *Hyatt.*

Type, *Meekoceras gracilitatis* White, Fossils of the Jura-Trias of Southeastern Idaho, 1879, p. 111; and Contrib. to Pal. No. 5, 1880, p. 112, pl. xxi, figs. 2, *a–d*.

Form compressed, discoidal, involute or evolute, sides flattened; venter narrow, either flattened or rounded, no keels or furrows; umbilicus narrow or wide; body-chamber short. Surface nearly smooth, or ornamented with radial lateral folds; no tubercles, spines, nor spiral ridges. Septa ceratitic, with rounded entire saddles and serrated lobes. The external lobe is short, and divided by a siphonal saddle; the two lateral lobes are longer and there is an auxiliary series present in most forms, consisting of a single lobe (serrated or goniatitic), or of a series of denticulations, some of which may be partly individualized into lobes.

The internal septa consist of a divided antisiphonal lobe, flanked by a single lateral, although in some species there may be internal auxiliaries.

Perhaps no other genus of ammonites has been so variously treated as *Meekoceras*, for the reason that it is very variable, and also because in the first description no type was expressly given, and three species differing in essential respects were simultaneously described, *Meekoceras aplanatum* White, *M. mushbachanum* White, *M. gracilitatis* White, in the order given. But in the diagnosis of the genus Hyatt first mentions *M. gracilitatis*. Thus, according to usage, either *M. aplanatum* or *M. gracilitatis* might be taken as the type. Of these only the latter agrees with the generic diagnosis, since it has the fourth lobe as an auxiliary series of denticulations, and does not have a distinct saddle between this lobe and the umbilical suture.

Besides the species mentioned, Hyatt also included in the list of species of this genus previously described species that have since been assigned to *Balatonites*, *Hungarites*, *Xenaspis*, and *Celtites*, which have clearly no relationship with the typical members of the genus.

The writer regards all species that agree with any one of the three species, *M. aplanatum*, *M. mushbachanum*, and *M. gracilitatis*, as belonging to *Meekoceras* in the broader sense.

Mojsisovics[1] was the next to treat of this genus, in which he included a number of species now assigned to *Proptychites* and *Beyrichites*, thus giving *Meekoceras* an unwarranted extension beyond the limits assigned by Hyatt. In a later paper Mojsisovics[2] still further extended the genus in one direction to take in forms now assigned to *Hedenstrœmia*, but limited on the other side to involute forms. All evolute, open-coiled forms were assigned along with *M. aplanatum* to *Xenodiscus* Waagen, although Mojsisovics confessed that this was purely because *Xenodiscus* seemed to be the ancestor of a different stock. None of the forms assigned by Mojsisovics to *Xenodiscus* agree with Waagen's genus, and they are no longer classed under it.

Meekoceras was next treated by Waagen[3], who regarded

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[1] See Bibliog. 21—p. 213.
[2] See Bibliog. 20—p. 79.
[3] See Bibliog. 38—p. 236.

M. gracilitatis as the type, and placed all other kindred but dissimilar forms under different genera, thus restricting the genus to narrower limits than was intended by Hyatt. The evolute forms without auxiliaries, such as *M. aplanatum*, were placed under a new genus, *Gyronites*, which would include most of the forms assigned by Mojsisovics to *Xenodiscus*. Species with a fourth lateral lobe followed by a series of auxiliary denticulations, such as *M. mushbachanum*, were assigned to the new genus, *Koninckites* Waagen. Forms in which the auxiliary series had no individualized lobe, but consisted of merely a few denticulations were assigned to *Kingites* Waagen.

C. Diener[1] regards *Kingites* and *Koninckites* merely as subgenera of *Meekoceras*, in which conclusion the writer agrees with him. In a later paper Diener[2] includes also *Aspidites* Waagen and *Beyrichites* Waagen under *Meekoceras*. But these two types are different from any included by Hyatt under the original description, and it seems best to let them stand as independent genera.

As thus defined, *Meekoceras* in the broader sense would include all species similar to the three typical forms, and the species nearest to *M. gracilitatis* White would be classed under *Meekoceras* in the limited sense.

Since *M. aplanatum* White has all the characters of *Gyronites* Waagen, all species similar to it are placed in it as a subgenus under *Meekoceras*.

Examination of the types in the United States National Museum has shown that *Meekoceras mushbachanum* White has all the characters assigned by Waagen to *Koninckites*, and since this species was one of the types of *Meekoceras*, all species similar to it are classed in the subgenus *Koninckites*.

Aspidites and *Beyrichites* are regarded by the writer as independent genera. The systematic position of *Prionolobus* Waagen is somewhat doubtful, but it should probably be placed as a subgenus under *Meekoceras*.

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[1] See Bibliog. 5—p. 46.
[2] See Bibliog. 3—p. 126.

F. Frech[1] has recently proposed to drop the family Meekoceratidæ and the genus *Meekoceras*, dividing the species belonging to that genus between *Ophiceras*, *Prionolobus*, and *Aspidites*, although all these genera were described after *Meekoceras*, which was first described in 1879, and fully illustrated in 1880. Frech's reasons for this change were that Hyatt included in his original diagnosis not only the three American species that differ in certain important characters, but also foreign species later assigned to *Balatonites*, *Xenaspis*, *Hungarites*, and *Celtites*. Of course, it was a mistake to include these elements under *Meekoceras*, but the citation of them as species under *Meekoceras* did not make any confusion as to the limits of the group. The three American species were fully described and figured, and one of them was certainly the type.[2] The fact that later writers extended *Meekoceras* to take in heterogeneous elements does not invalidate it. If such a rule in nomenclature should be accepted, almost every genus of ammonites would be thrown out, and a new name substituted.

As restricted in this paper, *Meekoceras* is confined entirely to the Lower Trias, in which horizon it is very abundant in California, Idaho, India, and Siberia.

Genus Meekoceras, s. str., *Hyatt*.

Type, *Meekoceras gracilitatis*, White.

The restricted genus is represented in America by a large number of undescribed species, in addition to the type. It is also common in Asia, some of the Asiatic species being nearly allied to the American forms.

Meekoceras gracilitatis *White*.

Plate XLII, Figs. 1-4; Plate XLIII, Figs. 3-4.

1879. *Meekoceras gracilitatis*, White, Bull. U. S. Geol. Sur. Terr. Vol. V. p. 114.

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[1] Lethæa Palæozoica, Bd. II, Lieferung 4, 1902, p. 630.

[2] Professor Hyatt told the writer, in June 1900, that he had regarded *Meekoceras gracilitatis* as the type.

1880. *Meekoceras gracilitatis*, White, 12th An. Rept. U. S. Geol. Sur. Terr. Part I, p. 115, pl. xxxi, figs. 2, *a–d*.

1902. *Prionolobus gracilitatis*, F. Frech, Lethæa Palæozoica, Bd. II, Lieferung 4, p. 631, fig. *a*.

Shell compressed, involute, discoidal, deeply embracing, outer whorl concealing three-fourths of the inner, and being indented to one-third of the height by the inner whorl. Umbilicus narrow, but open, the width being about one-sixth of the diameter of the shell. The whorl increases rather rapidly in height, the altitude being slightly more than twice the breadth of the whorl, and one-half of the total diameter of the shell. The sides are gently convex from the abruptly rounded umbilical shoulder; the greatest thickness of the whorl lies at a point even with the top of the inner whorl, thus giving a lenticular appearance to the shell. Venter flattened, biangular, with broad flat space and sharp shoulder angles.

Surface ornamented with low folds and radial striæ of growth, which in age cross the venter in faint corrugations. No true ribs nor spines are ever present.

Septa ceratitic, saddles all rounded and entire, lobes all serrated, ventral short, divided by a broad shallow siphonal saddle; first lateral broad and deeper, second lateral narrow as the ventral; auxiliary series consisting of a short straight row of denticulations following the third lateral saddle, forming merely an unindividualized lobe, which, however, is sharply distinguished from the saddle. The inner septa consist of a short divided antisiphonal lobe, with a single lateral.

The young are much more involute than mature forms, the umbilicus growing wider with age, and the whorls less deeply embracing. The relative width of the umbilicus is variable, also the abruptness of the umbilical shoulder.

Diener[1] thinks that White has confused two species in his figures of *Meekoceras gracilitatis*, and that plate xxxi, figure 2*b* in White's paper represents a different species from figure 2*a*. But the difference lies rather in the drawing than in the original specimens. The septa on White's original specimen are as in plate xxxi, figure 2*d* of White's paper, except that the denticulations are not sufficiently marked in the drawing, and the innermost saddle is more sharply defined from the auxiliary denticulations than in the figure.

Meekoceras gracilitatis White is nearly related to *M. boreale* Diener, of the Lower Trias of India and Siberia, but differs in not having the auxiliary series individualized,

[1] See Bibliog. 3—p. 132.

also in the wider umbilicus. There are, however, in the American Trias species with as narrow or even narrower umbilicus than *M. boreale*, but in them all the auxiliary series is as in *M. gracilitatis*.

Horizon and locality. *Meekoceras gracilitatis* was first found by Dr. A. C. Peale in the Aspen Mountains, southeastern Idaho, at two places, five miles west of John Gray's Lake, and about fifteen miles west of south from this lake. Professor Hyatt also found it in Wood Canyon, nine miles east of Soda Springs, Aspen Mountains. The writer has also collected numerous specimens of it at the latter locality, associated with *M. mushbachanum* White, *M. aplanatum* White, *Flemingites russelli* Hyatt & Smith, *Pseudosageceras* sp. nov., *Ussuria* sp. nov., *Nannites* sp. nov., *Aspidites* sp. nov., *Ophiceras* sp. nov., *Hedenstrœmia* sp. nov., and many other forms characteristic of the Lower Trias. The writer has also found this species to be abundant in the Meekoceras beds of the Union Wash, near the Union Spring, east side of Owen's Valley, Inyo Range, Inyo County, California, about fifteen miles southeast of Independence, associated with all the above mentioned forms except *Flemingites* and *Hedenstrœmia*.

The specimens figured in this paper were collected by the writer in Wood Canyon, Aspen Mountains, Idaho.

Subgenus **Gyronites** *Waagen*.

Type, *Gyronites frequens* Waagen, Fossils from the Ceratite Formation, 1895, p. 292, pl. xxvii, figs. 1–4.

Evolute, discoidal, laterally compressed, little embracing; wide, shallow umbilicus; whorls increasing slowly in height, and covering but a small portion of the inner volutions. Venter narrow, either biangular or rounded. Surface smooth, or ornamented only with radial striæ and low folds. Body-chamber supposed to be short, but little is known of this character. Septa partly ceratitic, all the saddles and part of the lobes being entire. The external lobe is divided into two unserrated branches by the siphonal saddle. The first lateral lobe is always serrated, the second usually not so; and there is sometimes a short auxiliary series of denticulations. The internal septa consist of a rather short divided antisiphonal lobe and a single lateral.

Diener[1] says that this group would coincide chiefly with

[1] See Bibliog. 3—p. 30.

Meekoceras, and that the rest of the species assigned to it by Waagen would fall partly under *Ophiceras* and partly under *Danubites*. Mojsisovics and Waagen formerly classed the species of *Gyronites* under *Xenodiscus*. Certainly the amount of involution should not be regarded as sufficient excuse for generic separation, and only the development stage can warrant such a separation. Now since *Meekoceras aplanatum* White, one of the original types of *Meekoceras* in the broader sense, has all the characters of *Gyronites*, the writer prefers to retain this name as a subgeneric title for the species of the group of *M. aplanatum*. *Gyronites* is found only in the Lower Trias of India, Siberia, Idaho and California, where it is represented by *M. aplanatum*, and by several new species, as yet undescribed.

Meekoceras (Gyronites) aplanatum White.

Plate XLI, Figs. 4-6.

1879. *Meekoceras aplanatum*, White, Bull. U. S. Geol. Sur. Terr. Vol. V, p. 112.

1880. *Meekoceras aplanatum*, White, An. Rept. U. S. Geol. Sur. Terr. Vol. XII, Part 1, p. 112, pl. xxxi, figs. 1, *a*, *b*, and *d*, (not fig. *c*, which is *Gyronites whiteanus* Waagen).

1886. *Xenodiscus aplanatus*, Mojsisovics, Arktische Triasfaunen, p. 75.

1895. *Xenaspis aplanatus*, Waagen, Salt Range Fossils, Vol. II, Fossils from the Ceratite Formation, p. 290.

1900. *Wyomingites aplanatus*, Hyatt, Cephalopoda, p. 556 (in Zittel-Eastman's Text-book of Palaeontology).

1902. *Ophiceras applanatum*, F. Frech, Lethæa Palæozoica, Bd. II, Lieferung 4, p. 661, fig. *e*.

Evolute, discoidal, laterally compressed; wide shallow umbilicus. Whorls increasing slowly in height, little embracing, outer whorl concealing but little of the inner, and being indented to less than one-fourth of its height by it. Breadth of whorl a little more than one-half of its height, and one-fifth of the total diameter of the shell; height of whorl a little more than one-third of the diameter of the shell. Width of umbilicus equal to the height of the whorl. Umbilical shoulders abruptly rounded, but not angular. Sides gently convex, venter flattened, narrow, with subangular ventral shoulders.

Surface ornamented with cross striæ and folds, which may become quite strong on the body-chamber.

Septa ceratitic, saddles all rounded and entire, lobes partly serrated, partly entire. The external lobe is divided by a siphonal saddle into two narrow branches which are very slightly serrated; these branches fall on the abdominal shoulder-angles. The first lateral lobe is distinctly serrated, longer

the external, and much wider; the second lateral is usually entire, although occasionally slightly denticulated. There is no auxiliary series. The internal septa consist of a short bifid antisiphonal lobe, and a short entire lateral, just inside the umbilical suture. These septa are very like those of *Xenaspis* Waagen, except in the difference in the sizes of the lobes. This resemblance becomes more important when it is known that *M. aplanatum* has a body-chamber at least three-quarters of a revolution in length.

The writer regards *Xenaspis* and *Gyronites* as being very closely related, and it is by no means impossible that *M. aplanatum* may eventually be shown to belong to the former genus.

M. aplanatum White resembles *Gyronites frequens* Waagen, but differs from the Asiatic species in lacking the auxiliary lobe. It also agrees in septa with *G. nangænsis* Waagen, but is slightly more involute, and has shorter lobes.

The relative dimensions of *M. aplanatum* are as follows:

Diameter	1.00
Height of last whorl	0.37
Height of last whorl from the preceding	0.27
Width of last whorl	0.20
Width of umbilicus	0.37
Involution	0.10

In small specimens the whorl is more robust, broader in proportion to its height, and more deeply embracing, although the form is always very evolute, even in early stages of growth. The young whorls are rounded, the angular venter being a character of adolescence. The adolescent shell agrees in all respects with *Lecanites* Mojsisovics, and this species gives a transition from that genus to *Meekoceras*. On this account the writer prefers to recognize *Gyronites* as a subgenus, or transitional group.

Hyatt[1] took *M. aplanatum* as the type of a new but undescribed genus, *Wyomingites*, but this statement was intended to refer to the form named by Waagen *Gyronites whiteanus*, and not to the typical *M. aplanatum*. It was unknown to Hyatt that Waagen had already renamed this form.

Horizon and locality. Lower Trias, *Meekoceras* beds, southeastern Idaho, Aspen Mountains, about five miles west of John Gray's Lake, also about fifteen miles a little west

[1]Cephalopoda 1900, p. 556.

of south from that lake; also at Wood Canyon nine miles east of Soda Springs, Idaho. The writer also found it in the same horizon in the *Meekoceras* beds of the Inyo Range, east side of Owen's Valley, on the Union Wash, near the Union Spring, about fifteen miles southeast of Independence. In Wood Canyon, Idaho, and Union Canyon, Inyo Range, California, the writer found along with it; *Meekceras gracilatitis* White, *M. mushbachanum* White, *Pseudosageceras* sp. nov., *Ussuria* sp. nov., *Ophiceras* sp. nov., *Danubites* sp. nov., *Nannites* sp. nov., and many other forms characteristic of the Lower Trias, besides a number of new genera.

The specimens figured in this paper were all collected by the writer in the *Meekoceras* beds of Wood Canyon, Aspen Mountains, Idaho, nine miles east of Soda Springs, along with the above mentioned forms, and in addition to these, *Flemingites* sp. nov., *Hedenstrœmia* sp. nov., *Xenaspis* sp. nov., and a large number of other species of more common genera.

Subgenus **Koninckites** *Waagen.*

1895. *Koninckites*, Waagen, Salt Range Fossils, Vol. II, Fossils from the Ceratite Formation, p. 258.
1895. *Koninckites*, Diener, Triadische Cephalopodenfaunen der Ostsibirischen Küstenprovinz, p. 53.
1896. *Koninckites*, Toula, Eine Muschelkalkfauna am Golfe von Ismid in Kleinasien, p. 177.
1897. *Koninckites*, Diener, Himalayan Fossils, Vol. II, Part I, Cephalopoda of the Lower Trias, p. 139.
1902. *Aspidites* (pars), Frech, Lethæa Palæozoica, Bd. II, Lieferung 4, p. 637.

Type, *Koninckites vetustus* Waagen, Fossils from the Ceratite Formation, p. 261, pl. xxvii, figs. 4–5.

Evolute, discoidal, laterally compressed, narrow venter, either flattened or rounded, sides flattened, and entire form not robust. Umbilicus wider than in typical members of *Meekoceras* s. str., and lateral ornamentation stronger, often forming coarse radial ribs or folds. Septa as in *Meekoceras* s. str., but the auxiliary lobe is individualized, followed by an auxiliary saddle, and this by a short series of denticulations, on the umbilical shoulder.

This subgenus embraces a number of species from the Lower Trias of the Salt Range, the Himalayas, Ussuri Bay, and the mouth of the Olenek River in Siberia. It

was not known to Waagen that *Meekoceras mushbachanum* White possessed the essential characters of *Koninckites*, for the published figures of the septa of that species are not exact. But since this is the case, and since *M. mushbachanum* was one of the types of *Meekoceras*, this group of species, characterized by the greater involution, the more rugose shell, and the fourth lateral lobe followed by the auxiliary denticulations, is regarded as a subgenus under *Meekoceras* in the broader sense. There are in the American Trias in California and Idaho several undescribed species that will fall under this subgenus.

Frech[1] proposes to drop *Koninckites*, referring the species described by Waagen under that name to *Aspidites*. While this is, no doubt, correct for some of the species, it is not correct for the type, nor for species like the type, of which *M. mushbachanum* is one.

Meekoceras (Koninckites) mushbachanum *White*.

Plate XLI, Figs. 1-3; Plate XLIII, Figs. 1-2.

1879. *Meekoceras mushbachanum*, White, Bull. U. S. Geol. Sur. Terr. Vol. V, p. 113.

1880. *Meekoceras mushbachanum*, White, An. Rept. U. S. Geol. Sur. Terr. Vol. XII, Part I, p. 114, pl. xxxii, figs. 1, *a-d*.

1902. *Prionolobus mushbachanus*, Frech, Lethæa Palæozoica, Bd. II, Lieferung 4, p. 631, fig. *c*.

Compressed, involute, discoidal, whorl rather deeply embracing, covering nearly three-fifths of the inner volution, and being indented to one-fourth of the height by it. Umbilicus wide, shallow, umbilical shoulders abruptly rounded. Sides more flattened than in *M. gracilitatis*, gently convex up to the rather narrowly rounded venter. Height of whorl twice its breadth, and nearly one-half of the entire diameter. Width of umbilicus nearly one-fourth of the total diameter of the shell. Greatest breadth of whorl at a point half way between base and venter.

Surface ornamented with sharp cross striæ, slightly curved, and with faint low folds, especially in age.

Septa ceratitic, saddles all rounded, lobes all serrated. Ventral lobe divided by a broad, shallow, siphonal saddle, the two divisions being serrated by about five denticulations. The first lateral is somewhat deeper and broader; the second lateral about one-half as deep as the first, and smaller, the first auxiliary is small and shallow, provided with several denticulations. Then

[1]Lethæa Palæozoica, Bd. II, Lieferung 4, 1902, p. 637.

follows a small auxiliary saddle, followed by a short row of denticulations on the umbilical shoulder. The internal septa consist of a moderately long antisiphonal lobe and a single lateral.

Horizon and locality. Lower Trias, Aspen Mountains, southeastern Idaho, *Meekoceras* beds, five miles west of John Gray's Lake, and fifteen miles a little west of south from that lake, also in Wood Canyon, nine miles east of Soda Springs, at the latter locality associated with *Meekoceras gracilitatis*, *M. aplanatum*, *Ussuria*, *Aspidites*, *Pseudosageceras*, *Ophiceras*, *Flemingites*, *Danubites*, *Nannites*, *Hedenstrœmia*, and many other forms. The writer also found it to be abundant in Union Canyon, near the Union Spring, Inyo Range, fifteen miles southeast of Independence, Inyo County, California, associated with practically the same fauna as in Idaho.

All specimens figured in this paper were collected by the writer in Wood Canyon, nine miles east of Soda Springs, Aspen Mountains, southeastern Idaho.

Genus Flemingites *Waagen.*

1892. *Flemingites*, Waagen, Records Geol. Sur. India, Vol. XXV, Part IV, p. 184.

1892. *Flemingites*, Waagen, Jahrb. k. k. geol. Reichsanstalt Wien, Vol. 42, Part 2, p. 380.

1895. *Flemingites*, Waagen, Salt Range Fossils, Vol. II, Fossils from the Ceratite Formation, p. 185.

1897. *Flemingites*, Diener, Himalayan Fossils, Vol. II, Part I, Cephalopoda of the Lower Trias, p. 90.

1902. *Flemingites*, Frech, Lethæa Palæozoica, Bd. II, Lieferung 4, p. 638.

1902. *Flemingites*, Frech, Centralblatt, für Min. Geol. und Pal., 1902, No. 5, Ueber Trias-Ammoniten aus Kaschmir, p. 134.

Type "*Ceratites*" *flemingianus* de Koninck. Quart. Jour. Geol. Soc. Lond, Vol. XIX, p. 10, pl. vii, fig. 1, from the Lower Trias of the Salt Range of India.

Form evolute, little embracing; wide shallow umbilicus; whorls robust, usually a little higher than wide, increasing very slowly in size; sides rounded, venter somewhat flattened and usually much narrower than the greatest breadth of the whorl. Strong lateral folds are often present, but these are never dichotomous, and never cross the venter. There are strong fine spir' ridges on all parts of the shell, and these usually appear also on the Body-chamber short, not greatly exceeding one-half a revolution. distinctly ceratitic, like those of *Meekoceras*, but usually with lo There are four lobes, the external, first and second laterals,

Waagen separated this group from *Ceratites*, in spite of its close agreement with that genus, and placed it under the *Leiostraca*, in spite of the coarse ribs that are often present. *Flemingites* is confined entirely to the Lower Trias, being found in that horizon in the Himalayas and the Salt Range in India, and in the Aspen Mountains of Idaho, where it is represented by several species.

Flemingites russelli *Hyatt & Smith* ms.

Plate XLII, Fig. 5; Plate XLIII, Figs. 5-6.

1904 (?)*Flemingites russelli* Hyatt & Smith, ms., The Triassic Cephalopod Genera of America, Professional Papers No.——— U. S. Geol. Sur. p.———, pl. i, figs. 1-3, pl. lxx, figs. 1-3.

Evolute, discoidal, latterly compressed, wide umbilicus; whorls not deeply embracing, outer whorl covering only one-third of the inner, and indented by it to only one-sixth of the height. The increase in height of the whorls is rapid. Umbilicus wide and shallow, umbilical shoulders rounded; sides gently convex; venter narrow and somewhat rounded; whorls twice as high as broad.

Sides ornamented with rather strong folds on mature shells, nearly smooth on young shells. Surface of shell ornamented with fine spiral lines. Septa ceratitic, with four ceratitic lobes, and three rounded saddles on each side. The external lobe is divided by a deep siphonal saddle; the first lateral is twice as long as the external, the second lateral is narrow, and the auxiliary lobe consists of four or five denticulations, forming a broad lobe.

The spiral lines did not show on the specimen photographed, but were distinct on others.

Horizon and locality. In the *Meekoceras* beds Lower Trias, of Wood Canyon, Aspen Mountains, nine miles east of Soda Springs, southeastern Idaho, associated with *Meekoceras gracilitatis* White, *M. mushbachanum* White, *M. aplanatum* White, *Aspidites*, *Ussuria*, *Ophiceras*, *Hedenstrœmia*, *Danubites*, *Nannites*, and many other forms.

Genus **Beyrichites** *Waagen.*

1895. *Beyrichites*, Waagen, Salt Range Fossils II, Fossils from the Ceratite Formation, p. 160.

1896. *Beyrichites*, Arthaber, Cephalopodenfauna der Reiflingerkalke, II, p. 228.

1896. *Beyrichites*, Toula, Eine Muschelkalkfauna am Golfe von Ismid in Kleinasien, p. 172.

1897. *Beyrichites*, Diener, Himalayan Fossils, II, Part 1, Cephalopoda of the Lower Trias, p. 74.

1898. *Beyrichites*, Tornquist, Neuere Beiträge zur Geol. und Pal. Umgebung von Recoaro, etc., p. 658.

Type, *Ammonites reuttensis* Beyrich, 1867, Cephalopoden des Muschelkalkes der Alpen. Abhandl. k. Akad. Wiss. Berlin, 1866, p. 113, pl. i, fig. 4.

Involute, laterally compressed, deeply embracing; umbilicus narrow, sides slightly convex, venter narrowly rounded. Sides ornamented with weak ribs which usually have a falciform bend. Septa of the ceratitic type, but with the saddles slightly denticulated, in the transition to becoming ammonitic.

Waagen established this genus to include "*Meekoceras*" *reuttense* Beyrich, *M. khanikofi* Oppel, and *M. maturum* Mojsisovics, of the Muschelkalk of the Alps, but he placed these in the family Ptychitidæ. Diener has shown that *Beyrichites* does not belong to the Ptychitidæ, but he went to the extreme of classing it as a subgenus under *Meekoceras*.

On account of the specialization shown by its sculpture and the denticulated saddles the writer considers this as an independent genus, in the family Meekoceratidæ, as marking a distinct stage in the evolution of the group. As thus defined this genus is confined to the Middle Trias of the Alps, India, Asia Minor, and Nevada.

E. von Mojsisovics[1] has recently classed *Beyrichites* with the Ceratitidæ, and regards it as a probable offshoot from *Dinarites*.

Beyrichites rotelliformis *Meek*.

Plate XLV, Fig. 5; Plate XLIII, Figs. 13-14.

1877. *Gymnotoceras rotelliforme*, Meek, U. S. Geol. Expl. Fortieth Parallel, Vol. IV, p. 111, pl. x, figs. 9-9*a*.

Involute, discoidal-lenticular, laterally compressed. Whorl high and increasing rapidly in height, with flattened-convex sides and narrowly rounded venter. Umbilicus narrow, umbilical shoulders abruptly rounded, with very steep inner walls. The height of the whorl is slightly greater than one-half of the total diameter, and the width is two-thirds of the height. It is indented to about two-sevenths of its height by the inner whorl. The width of the umbilicus is about one-sixth of the total diameter of the shell.

Surface ornamented with numerous fine flexuous ribs and radial striæ of growth, with sigmoidal curve on the flanks, and a sharp forward bend just below the abdominal shoulders. These ribs are strongest on the flanks, and become obsolete near the venter. They do not become obsolete on the mature shell, although they are stronger on the young shell.

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[1] Cephalopoden der Hallstätter Kalke, Bd. I, SupplementHeft, 1902, p. 331.

The septa are ceratitic, but the saddles are also slightly denticulated. The external lobe is divided by a short siphonal saddle; the first lateral is large and slightly digitate; the second lateral is smaller and simpler; this is followed by a similar but smaller third lateral. The true auxiliaries consist only of denticulations below the auxiliary saddle. The septa are not like those of *Ceratites (Gymnotoceras) blakei* Gabb, with which species Gabb united it.

The young shells are more robust, evolute, and have rougher sculpture.

This species was erroneously assigned by Hyatt to his genus *Gymnotoceras*, but it agrees in all respects with *Beyrichites*. It is not impossible that this genus may belong to the Ceratitidæ.

Horizon and locality. Middle Trias, *Daonella* beds, New Pass, Desatoya Mountains, Nevada, and in the West Humboldt Range, Nevada, in Buena Vista Canyon, and on the divide between Troy Canyon and the south fork of American Canyon. The figured specimen was collected by the writer at the latter locality, associated with *Anolcites whitneyi*, *Acrochordiceras hyatti*, *Gymnotoceras blakei*, and many other characteristic Middle Triassic species.

Genus **Eutomoceras** *Hyatt*.

1877. *Eutomoceras*, Hyatt, U. S. Geol. Expl. Fortieth Parallel, Vol. IV, p. 126.

Type, *Eutomoceras laubei* Meek, U. S. Geol. Expl. Fortieth Parallel, Vol. IV, p. 126, pl. x, figs. 8, 8 *a*.

Involute, discoidal, laterally compressed, with flattened sides, narrow venter, distinct umbilical shoulders, and narrow acute venter surmounted by a sharp solid keel without marginal furrows. Surface ornamented with radial dichotomous ribs that branch out from knots on the umbilical shoulders, curve upwards on the sides, and bend sharply forward on the shoulders to the keel. Also small knots occur on the lateral ribs at irregular intervals, not arranged in spiral lines.

The septa are ceratitic, consisting of a divided ventral lobe, two principal laterals, and several smaller auxiliaries. The saddles are all rounded and entire, while the lobes are distinctly serrated. Internal septa and length of body-chamber unknown.

This genus greatly resembles *Hungarites* Mojsisovics, and differs from that group chiefly in the distinct sickle-shaped ribs, the irregular knots, and the extremely high keel. It has very probably developed out of *Hungarites*, for its young stages are almost identical with mature forms

of that genus. The foregoing description is based partly on Meek's type specimen, which was imperfect, but chiefly on perfect specimens of this and one other species, collected by the writer in the West Humboldt Range, Nevada.

This genus has been extended to take in the group of *Ammonites sandlingensis* Hauer of the Mediterranean region, but all those species have ammonitic septa, usually a hollow keel, and long body-chamber, and so fall under the Tropitidæ, but they are left for the present with *Eutomoceras.*

Eutomoceras s. str. is confined to the Middle Trias, in which horizon it is rather common in the West Humboldt Range of Nevada, in the *Daonella* beds, associated with numerous nodose ceratites.

Eutomoceras dunni *Smith*, sp. nov.

Plate XLIII, Fig. 11; Plate XLIV, Fig. 4.

Shell involute, discoidal, laterally compressed. Whorls high, deeply embracing, and rather deeply indented by the inner volution. Sides slightly convex, sloping from the greatest breadth at the umbilical shoulder to the narrow acute venter, with abruptly rounded abdominal shoulders. Venter surmounted by a high keel, without marginal furrows. Umbilical shoulders abruptly rounded, umbilicus narrow and deep. The height of the whorl is one-half the total diameter of the shell, and the width is two-thirds of the height; it is indented to one-fifth of the height by the inner whorl. The width of the umbilicus is one-fifth of the diameter of the shell. The surface is ornamented with coarse ribs that bifurcate from coarse knots on the umbilicus, and branch again about one-third of the way up the flanks, then curve sharply forward on the abdominal shoulders to the base of the keel. There are frequent knots on the lateral ribs, but these are not arranged in regular spiral rows, and the intercalary ribs do not fork on the flanks.

The septa are ceratitic, with rounded entire saddles and serrated lobes, like those of *Eutomoceras laubei* Meek.

Eutomoceras dunni is nearly related to *Eutomoceras laubei* with which it is associated, but differs in its more robust whorl, stronger sculpture, higher keel, and slightly narrower umbilicus.

The dimensions of the type specimen, figured on plate xliv, figure 4, and plate xliii, figure 11, are as follows:

Diameter	42	mm.
Height of last whorl	21	mm.
Height of last whorl from the preceding	17	mm.
Width of last whorl	13	mm.
Involution	4	mm.
Width of umbilicus	8.5	mm.

Horizon and locality. Upper part of Middle Trias, *Daonella* beds, West Humboldt Range, Nevada, on the divide between Troy Canyon and the south fork of American Canyon, associated with *Ceratites vogdesi*, *Anolcites meeki*, *A. whitneyi*, *A. hyatti*, *Beyrichites rotelliformis*, *Daonella dubia*, and many others. The specific name is given in honor of Mr. L. F. Dunn, of Winnemucca, Nevada, to whom the writer is indebted for the discovery of this locality.

Genus **Ceratites** *de Haan.*

Type, *Ceratites nodosus* Brugière, figured by de Haan in his Monographiæ Ammoniteorum et Goniatiteorum Specimen, 1825, p. 39.

This genus, which is the commonest and most widely distributed of the Middle Triassic ammonites, as well as the most characteristic, is the hardest to define. After de Haan introduced the name *Ceratites*, all ammonites with ceratitic septa were assigned to this genus, thus including species from the most diverse genera and even families. The type species is common in the Germanic basin, but until recently was unknown outside of the province, and so most writers that have dealt with *Ceratites* have described species from other provinces and other regions. It could not be expected that they would all agree with the type, and hence these writers have had free rein to extend the genus as it pleased them. They have extended the genus, which was allowable and necessary, but there has been little uniformity in their extensions. Further than this, they have overlooked the fact that the original type must be considered as the typical form, and in many cases have come to regard the group of *Ceratites nodosus* as exceptional, and the Asiatic and Alpine species as normal, which was unwarranted.

Waagen's (38) monograph was the first to give a comprehensive, elastic, and exact definition of the genus *Ceratites*, and even his work was based entirely on Asiatic species, which depart considerably from the Germanic prototypes. Dr. A. Tornquist was the first to make a systematic comparison of the Germanic ceratites with those of the Alpine and other groups, and to him is due the reëstablishment of the group of the *Nodosi* in its real importance as the typical and normal forms.

This group embraces forms of moderate involution, not deeply embracing, but increasing rather rapidly in diameter, thus causing the umbilicus to be wide. The whorls are subquadrate in cross-section, usually higher than wide, with square abdominal shoulders and somewhat flattened venter. The sculpture consists of ribs starting out from the umbilicus, and running nearly straight up the sides, either single or bifurcating. These ribs do not usually extend beyond the abdominal shoulders, which separate the sculptured sides from the ventral portion usually destitute of all sculpture, except in a few groups where there is a low ventral ridge. The umbilical and abdominal shoulders are often provided with strong knots, which may also occur on the lateral ribs; these knots, however, are not set close together as in *Balatonites* and *Trachyceras*.

The septa consist of rounded saddles and serrated lobes, and in the more specialized forms even the saddles may be denticulated. The external lobe is divided by a siphonal saddle into two narrow branches; there are two laterals, and a series of several small auxiliaries, which may be reduced to mere denticulations of a nearly straight saddle. The internal (antisiphonal) lobe is long, narrow, and bifid, flanked by a lateral and an auxiliary series, corresponding closely to the outside septa. The body-chamber is rather short, not more than three-quarters of a revolution in length.

Ceratites has the greatest resemblance to *Hungarites*, from which it differs in the rugose sculpture, the greater evolution, the absence of abdominal shoulder keels, and the almost total absence of a true ventral keel. The two genera agree exactly in septation, and this resemblance indicates their kinship.

Hungarites is the older and more primitive form, and may be the ancestor of *Ceratites*, although this is not likely. E. von Mojsisovics has always regarded *Dinarites* as the radicle of the group, but this genus appears not to have existed in the older part of the Lower Trias, in beds older than those containing *Ceratites*, while *Hungarites* occ

even in the Permian. The latter genus is usually classed with the *Leiostraca*, but this artificial classification can not separate groups that are manifestly closely allied.

As to the more remote ancestor of *Ceratites*, all species of this group go through a stage resembling *Tirolites*, which is probably the primitive radicle not only of *Ceratites*, but also of the entire family of the Ceratitidæ. This group has usually been regarded as an offshoot of the goniatite family Glyphioceratidæ, to which, however, the young of *Ceratites* have no resemblance. The typical members of the Ceratitidæ, in their adolescent and late larval stages, resemble the Prolecanitidæ, and probably are connected with that group through *Paralecanites*.

Ceratites is characteristic of the Middle Trias of the Mediterranean, Oriental, Arctic, and American regions, but in India and Siberia is found also in the upper part of the Lower Trias. And it has also been described by Mojsisovics from the Upper Trias of the Alpine province, although the forms ascribed to *Ceratites* are very different from the original type of the *Nodosi* and are probably not congeneric with it. The genus is represented in Nevada by about thirty species belonging partly to the group of *Ceratites nodosi* partly to *Ceratites geminati*, and partly to *Ceratites polaris*.

Ceratites vogdesi *Smith*, sp. nov.

Plate XLIII, Figs. 7-8; Plate XLIV, Fig. 1.

Form evolute, robust, whorls subquadratic, a little higher than wide, with rather broad venter raised in the middle to a low central ridge, and with abrupt subangular ventral shoulders. The umbilicus is rather wide and deep, with abruptly rounded umbilical shoulders. The outer whorl conceals more than one-half of the inner, and is indented by it to about one-half of the height. The width of the whorl is about four-fifths of the height, and the height is about three-sevenths of the total diameter. The width of the umbilicus is one-third of the total diameter.

The surface is ornamented with coarse, radial ribs that start out from the umbilical shoulders, develop strong spines about two-thirds of the way up the flanks, and again on the abdominal shoulders. There are eight of the principal ribs and lateral knots to a revolution, and twice as many spines on the shoulders. The intermediate ribs are fainter and do not develop spines.

The septa are ceratitic, with rounded entire saddles and serrated lobes. The external lobe is divided by a shallow siphonal saddle into two short branches; the first lateral is deeper and broader; the second lateral about one-half as large, and the auxiliary lobe consists of a straight series of denticulations, distinctly separated from the third lateral saddle.

This species is a genuine nodose ceratite, and seems to belong to the narrow group of *Ceratites nodosus*. It is nearest to *C. evolvens* Hauer[1] but is more evolute, and has fewer ribs and stronger spines.

The dimensions of the type specimen, figured on plate xliv, are as follows:

Diameter	67 mm.
Height of last whorl	29 mm.
Height of last whorl from the preceding	24 mm.
Width of last whorl	24 mm.
Involution	5 mm.
Width of umbilicus	18 mm.

Horizon and locality. Upper part of the Middle Trias, *Daonella* beds, West Humboldt Range, Nevada, on the divide between Troy Canyon and the south fork of American Canyon, associated with *Anolcites whitneyi*, *A. hyatti*, *A. meeki*, *Protrachyceras americanum*, *Acrochordiceras hyatti*, *Beyrichites rotelliformis*, *Eutomoceras laubei*, *Sageceras gabbi*, *Daonella dubia*, and many other characteristic species. In this bed there are more than twenty species of genuine nodose *Ceratites*, most of them apparently new species, though many are closely allied with Indian and Mediterranean forms.

The specific name is given in honor of Col. A. W. Vogdes, U. S. A., to whom the writer is indebted for valuable aid in the bibliography of the Trias.

Subgenus Gymnotoceras *Hyatt*.

1877. *Gymnotoceras*, Hyatt, in F. B. Meek, U. S. Geol. Expl. Fortieth Parallel, Vol. IV, p. 110.

Type, *Ammonites blakei* Gabb, Pal. Calif., 1864, Vol. I, p. 24, pl. iv, figs. 14-15; and F. B. Meek, U. S. Geol. Expl. Fortieth Parallel, Vol. IV, p. 112, pl. x, figs. 10, *a-b*, (not pl. x, fig. *c*, nor pl. xi, fig. 6).

[1] See Bibliog. II—pl. vi, fig. 4.

Subgeneric characters: Form involute, laterally compressed, robust whorls, deeply embracing, not deeply indented by the inner volutions. Sides convex, abdominal shoulders rounded, venter high, and raised in the middle in a keel-like ridge. Umbilicus moderately wide, exposing the inner whorls. Surface ornamented with sigmoidal ribs, which branch on the sides, and swing sharply forward across the rounded shoulders to the median ridge. There are no umbilical nodes and none on the flanks, but in age the ends of the ribs tend to form knots on the shoulders, although these are never pronounced. The body-chamber seems to be long, nearly a revolution, but the genus cannot be classed with the Tropitidæ, on account of its ontogeny, which is that of the Ceratitidæ.

Septa ceratitic, lobes serrated, and saddles slightly denticulated.

Mojsisovics[1] says that *Gymnotoceras* is merely a synonym of the group of *Ceratites geminati*, characteristic of the Arctic Trias, but it seems to the writer that its characters are sufficiently distinct from those of *Ceratites nodosus* to warrant giving subgeneric rank to the group, which would then include most species of the *Ceratites geminati*.

As thus characterized, *Gymnotoceras* is diagnostic of the Middle Trias, in which horizon it occurs in Nevada and in northern Siberia. It does not seem to the writer, however, that all species of the *Ceratites geminati* should be included in *Gymnotoceras*, but only those with the sigmoidal lateral ribs, raised keel, and absence of lateral spines.

Ceratites (Gymnotoceras) blakei *Gabb.*

Plate XLIII, Figs. 9–10; Plate XLIV, Figs. 2–3.

1864. *Ammonites blakei*, Gabb, Pal. Calif., Vol. I, p. 24, pl. iv, figs. 14–15.
1877. *Gymnotoceras blakei*, Meek, U. S. Geol. Expl. Fortieth Parallel, Vol. IV, p. 113, pl. x, figs. 10 *a–c* (not pl. xi, fig. 6).

Form involute, robust, laterally compressed, whorl deeply embracing, but not deeply indented by the inner volution. Sides flattened-convex, venter high, and narrowed to a median keel. Abdominal shoulders narrow and sloping in early maturity, more abrupt in later age. Umbilicus rather narrow and deep; umbilical shoulders abruptly rounded, with steep inner walls. The height of the whorl is about one-half of the total diameter, and the width is three-fourths of the height. The indentation is one-fourth of the height. The width of the umbilicus is about one-fifth of the total diameter.

The surface is ornamented with strong radial dichotomous ribs that branch on the flanks about one-third of the way from the umbilicus, and bend sharply forward on the abdominal shoulders, becoming obsolete on the

[1] See Bibliog. 20—p. 23.

median ridge. The septa are ceratitic, but both lobes and saddles are denticulated.

In youth the form is more evolute and robust, and the cross-section of the whorl is nearly circular, with the exception of the impressed zone. The ribs are fine and much straighter than at maturity, and in the earliest stages are present only on the umbilical shoulders.

The length of the body-chamber is nearly or quite a complete revolution, and this increases the resemblance to *Paratropites*, but the young stages are not like those of the Tropitidæ.

G. von Arthaber[1] has described in the genus *Reiflingites* a somewhat similar group, that resembles *Ceratites* in form, but differs in the long body-chamber. The writer, however, is not of the opinion that the length of the body-chamber is of paramount taxonomic value.

Horizon and locality. Middle Trias, *Daonella* beds, West Humboldt Range, Nevada, in Star Canyon, Cottonwood Canyon, and on the divide between Troy Canyon and the south fork of American Canyon. The figured specimens were collected by the writer at the last locality, associated with *Beyrichites rotelliformis*, *Acrochordiceras hyatti*, *Anolcites whitneyi*, *A. meeki*, and many other characteristic Middle Triassic species.

Genus **Trachyceras** *Laube.*

This genus was named by Laube[2] with "*Ceratites*" *aon* Muenster as the type. Since that time Mojsisovics has extended and redefined the genus, dividing it into three groups, or subgenera, *Trachyceras* s. str., *Anolcites*, and *Protrachyceras*.

Subgenus **Protrachyceras** *Mojsisovics.*

1893. *Protrachyceras* Mojsisovics, Cephalopoden der Hallstätter Kalke, II, p. 618.
1896. *Protrachyceras* Mojsisovics, Beitr. Kennt. Obertriadischen Cephalopoden-Faunen des Himalayas, p. 646.
1898. *Protrachyceras* Tornquist, Zeitschr. Deutsch. Geol. Gesell. Bd. L., Heft 4, p. 659.

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[1] See Bibliog. 1—p. 72.

[2] Ueber Ammonites aon und Verwandte Arten, Sitzb. k. Akad. Wiss. Wien, Bd. LIX, p. 7.

No type is expressly given by Mojsisovics for this subgenus, but the first species mentioned is *Trachyceras chiesense* Mojsisovics[1], which is merely a fragment, and could hardly have been the typical form. The first form described is *Trachyceras rudolphi* Mojsisovics, which is much more characteristic, though not nearly so common nor so well known as many other species cited as belonging to this group. If the author had chosen one particular species as the type, it would probably have been *Trachyceras archelaus* Laube, which has all the characters cited in the diagnosis, is well known in all its details, and is so common as to be chosen as a zone fossil.

Protrachyceras is characterized by its short body-chamber, compressed, but robust, whorls, moderately involute form, open umbilicus, and central abdominal furrow. The ribs are provided with spines arranged in spiral rows, and the ventral furrow is bounded by only a single row of tubercles on each side. This is the character that distinguishes it from *Trachyceras* s. str., which possesses a double row of knots on each side. Most species of *Protrachyceras* are more evolute than those of *Trachyceras* s. str., but this character is not constant, and in the opinion of the writer the separation of the two groups is purely artificial, without either stratigraphic or phylogenic value.

Subgenus **Anolcites** *Mojsisovics.*

1893. *Anolcites*, Mojsisovics, Cephalopoden der Hallstätter Kalke, Bd. II, p. 621.

In naming this subgenus Mojsisovics did not select any species as the type, but the first one mentioned under the description is *Trachyceras doleriticum* Mojsisovics[2]. *Anolcites* differs from *Trachyceras* s. str. in being more evolute, with wider umbilicus, and lower whorls. The ventral furrow is scarcely developed, and the ribs cross the venter, although a row of tubercles is developed on each side of

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[1] See Bibliog. 21—p. 95, pl. xxxiv, fig. 4.

[2] See Bibliog. 21—p. 103, pl. xiii, fig. 5; pl. xxxvii, fig. 1.

the center, giving a resemblance to *Protrachyceras*. The septa are usually ceratitic, the saddles being mostly rounded and entire. The ribs and spines are like those of *Trachyceras* s. str. and *Protrachyceras*.

This subgenus ranges from the upper Muschelkalk to the middle of the Upper Trias. In America it is known only in the upper part of the Middle Trias of Nevada, where it is represented by *T. whitneyi* Gabb, *T. meeki* Mojsisovics, *T. hyatti* Smith, sp. nov., and by several undescribed species.

Trachyceras (Anolcites) hyatti *Smith*, sp. nov.

Plate XLIII, Fig. 12; Plate XLV, Figs. 1-2.

Evolute, whorls robust, little embracing, and little indented by the inner whorls. Cross-section quadratic, a little higher than wide. Venter broad and flat. Umbilical shoulders abruptly rounded, ventral shoulders square. Sides convex. Umbilicus very wide. The sculpture is rugose; coarse ribs start out from the umbilicus, and the alternate ones bifurcate at lateral spines half way up the sides, the two branches ending in strong spines on the ventral shoulders. These shoulder knots alternate on the two sides, and are continued in ridges diagonally across the venter. There is no ventral furrow, but the marginal knots are higher than the flattened space.

In youth there are strong umbilical knots, but with increasing age these move up the sides as far as the middle, becoming the lateral knots where the ribs branch.

Anolcites hyatti is very closely allied to *A. whitneyi* Gabb[1], but differs from Gabb's species in being more evolute, and in having coarser sculpture and stronger spines. In *A. whitneyi* the whorl is more flattened, and the angle below the shoulders is less pronounced. The adolescent shells of *A. hyatti* are more involute and have a broader whorl than those of *A. whitneyi*, and the ribs are fewer in adolescence as well as at maturity.

The young stages are very similar to *Ceratites altecostatus* Arthaber[2], and show a transition from *Ceratites* to *Anolcites*. F. von Hauer has described a species, *Ceratites*

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[1] See Bibliog. 9–p. 23, pl. iv, fig. 11 (not 12 and 13), which is *Protrachyceras americanum* Mojsisovics.

[2] See Bibliog. 1—p. 59, pl. v, figs. 7 *a-d*.

crassus[1], that closely resembles *Anolcites hyatti*, but the Austrian species is more evolute, and has weaker knots or spines.

The septa are ceratitic, like those of *A. whitneyi*.

While *Anolcites hyatti* was found associated with *A. whitneyi*, it is much more primitive. The former species is transitional from *Ceratites*, and the latter forms a connecting link with *Protrachyceras*.

Horizon and locality. Upper part of the Middle Trias, *Daonella* beds, West Humboldt Range, Nevada, on the divide between Troy Canyon, and the south fork of American Canyon, about four miles south of Foltz Post Office, associated with *Anolcites whitneyi*, *A. meeki*, *Protrachyceras americanum*, *Beyrichites rotelliformis*, *Acrochordiceras hyatti*, *Ceratites nevadanus*, *Ceratites vogdesi*, *Sageceras gabbi*, *Celtites halli*, *Eutomoceras laubei*, *Daonella dubia*, and many other species characteristic of the upper horizon of the Middle Trias.

The specific name is given in honor of the late Professor Alpheus Hyatt.

Trachyceras (Anolcites) meeki *Mojsisovics.*

Plate XLV, Figs. 3-4.

1882. *Trachyceras meeki*, Mojsisovics, Cephal. Medit. Triasprovinz, p. 108.
1877. *Trachyceras judicaricum*, Meek, U. S. Geol. Expl. Fortieth Parallel, Vol. IV, p. 118, pl. xi, figs. 1, 1*a* (not *Trachyceras judicaricum* Mojsisovics).

Form moderately evolute, robust, deeply embracing, but not deeply indented by the inner volution. Whorl increasing rather rapidly in height. Umbilicus wide and deep. Umbilical shoulders abrupt, flanks gently convex, abdominal shoulders gently rounded. Venter narrow, with deep central furrow. Surface ornamented with strong radial ribs and fine spiral rows of knots. The ribs bundle in knots on the umbilical shoulder, curve gently forward on the flanks, and cross the venter almost without interruption. There are rows of knots on the umbilical shoulder, on the ridge bordering the ventral furrow, and three rows on the flanks. The strongest knots are on the ventral borders. The ribs do not bundle in threes as shown in the rather diagrammatic drawing of the type published by Meek. There are usually two ribs branching out from an umbilical tubercle, and the alternate

[1] See Bibliog. 10—Bd. LXIII, p. 259, pl. viii, figs. 1 and 2.

ribs usually do not bifurcate. The knots bordering the venter do not lie opposite each other, but in alternate position.

At extreme maturity the ribs become weaker and the knots stronger, so that young shells and mature shells are quite different in appearance.

The ventral furrow is quite distinct, although the ribs may still be traced across it. In adolescence and early maturity the furrow is not developed, and the ribs on the venter are strong. In this character the species is intermediate between *Anolcites* and *Protrachyceras*.

Meek identified this species with *Trachyceras judicaricum* Mojsisovics of the Alpine province, from which it differs greatly in its coarser and fewer ribs and knots.

Horizon and locality. Middle Trias, *Daonella* beds, West Humboldt Range, Nevada, Cottonwood Canyon, and on the divide between Troy Canyon and the south fork of American Canyon. The figured specimens were collected by the writer at the last locality, associated with *Ceratites vogdesi*, *Anolcites whitneyi*, *Beyrichites rotelliformis*, *Gymnotoceras blakei*, etc.

Trachyceras (Protrachyceras) shastense *Smith*, sp. nov.

Plate XLVI, Fig. 9-9*a*; Plate XLVIII, Figs. 3-4.

Form involute, subrobust, laterally compressed, whorls deeply embracing, and deeply indented by the inner volutions. Sides flattened, venter narrow and rounded, with shallow ventral furrow. Umbilicus narrow, exposing only the umbilical shoulders of the inner whorls. The height of the whorl is more than one-half the diameter, and the width is two-thirds of the height; the whorl is impressed to more than one-fourth of its height by the inner volution. The width of the umbilicus is slightly more than one-seventh of the total diameter of the shell.

The surface is ornamented with fine dichotomous falcoid radial ribs, and fine spiral rows of knots on the ribs. There are about eleven of the spiral rows of knots, which are rudimentary spines. As the shell grows older the number of rows is augmented by intercalating secondary rows, smaller than the primary. The row of spines bordering the ventral furrow is the coarsest, as is the case with most of the *Trachycerata*.

Trachyceras shastense is most nearly related to *T. lecontei* Hyatt & Smith[1], with which it is associated, but differs from it in the more robust whorl, and coarser sculpture; the radial ribs are coarser, and the spiral rows of knots are coarser

[1] Ms. The Triassic Cephalopod Genera of Americ[a]
Sur. 1904, pl. 44, figs. 1-2; pl. 45, figs. 1-9; pl. 46, fig

6)

and fewer. It differs from *Trachyceras attila* Mojsisovics[1], in being less robust, and in finer sculpture, also in the somewhat more complex lobes.

Horizon and locality. Upper Trias, Karnic stage, zone of *Tropites subbullatus*, Shasta County, California, Brock Mountain, on trail from Squaw Creek to Pitt River, six miles northeast of the Bully Hill Mine; associated with *Tropites subbullatus*, *Paratropites sellai*, *Proclydonautilus triadicus*, *Halobia superba*, etc.

Genus Tropites *Mojsisovics.*

1875. *Tropites* (pars), Mojsisovics, in M. Neumayr, Die Ammoniten der Kreide, und die Systematik der Ammonitiden. Zeitschr. Deutsch. Geol. Gesell., 1875, p. 889.

1879. *Tropites* (pars), Mojsisovics, Vorläufige kurze Uebersicht der Ammoniten-Gattungen der Mediterranen und Juvavischen Trias, p. 136.

1893. *Tropites* (pars), Mojsisovics, Cephalopoden der Hallstätter Kalke, II, p. 184.

1896. *Tropites* (pars), Mojsisovics, Beitr. Kennt. Obertriadischen Cephalopoden-Faunen des Himalaya, p. 39.

Type, *Ammonites subbullatus* Hauer.

Generic characters: Moderately evolute whorls, not deeply embracing, and not deeply indented by the inner volution. Umbilicus open, and deep, with steep inner walls. Whorls usually broader than high, with angular prominent umbilical shoulders, and arched venter that may be either broad and low, or helmet-shaped. At maturity the whorls are often contracted, showing egression, so that the body-whorl is lower and narrower than the inner volutions. The cross-section is usually trapezoidal, and in the typical forms there are no flanks, for the venter is so flattened that it begins at the umbilical shoulders. Surface ornamented with strong umbilical knots, from which dichotomous start out curving gently across the sides to near the middle of the venter, upon which a strong keel is developed, usually with marginal furrows at which the ribs end. The surface of the shell has also spiral lines, which are not visible on the cast. No constrictions appear on the shell, and no knots except on the umbilical shoulders. The body-chamber is very long, more than a complete revolution.

The septa are ammonitic, but not deeply digitate, the number of the lobes varying with the shape of the whorl, but always of the dolichophyllic type.

Tropites is confined to the Karnic and Noric stages of the Upper Trias, in which horizons it occurs in the Alps,

[1] See Bibliog. 23—II, p. 633, pl. clxix, figs. 6–9; pl. clxx, figs. 1–2.

in the Himalayas, and in California, where it is represented by *Tropites subbullatus* Hauer, *T. torquillus* Mojsisovics, *T. dilleri* Smith, sp. nov., and many other species.

Tropites dilleri *Smith*, sp. nov.

Plate XLVI, Figs. 3-4; Plate XLVII, Fig. 3.

Involute, robust, whorls broad and helmet-shaped, curving gently from the subangular umbilical shoulder to the venter, without any abdominal shoulders. The umbilicus is rather narrow, with steep inner walls, exposing the umbilical shoulders of the inner whorls. There are weak umbilical knots, and from these faint ribs run forward with a gentle curve over the flanks. There are also distinct fine spiral lines covering the entire shell. The ribs show on the cast as well as the outer shell, while the spiral lines are visible only on the outer shell. In the middle of the venter there is a low keel, bordered by deep keel furrows, which show much more distinctly on the cast than on the outer shell.

The height of the whorl is less than one-half the diameter of the shell, the width is one and three-fifths times the height, and the whorl is indented to more than one-third of the height by the inner volution. The umbilicus is about one-sixth of the total diameter of the shell, becoming wider and showing egression with age. Also the whorl becomes higher and narrower in proportion, as maturity advances.

The septa are ammonitic, dolichophyllic, exactly like those of *Tropites subbullatus*, to which *T. dilleri* is nearly related.

It differs from *T. subbullatus* only in the narrower, higher whorl, but this difference is constant even in the early adolescent stages. *T. dilleri* is intermediate between *T. subbullatus* and *T. torquillus* ; it differs from the latter species in the broader, lower whorl, and in the slightly wider umbilicus. It may be identical with the form described by Mojsisovics[1] as a variety of *Tropites torquillus*, which differs from the species to which it is ascribed, in the broader whorl, and wider umbilicus. *T. dilleri* differs from *T. discobullatus* in these same characters, only to a greater degree, for that species is more compressed even than *T. torquillus*. It seems to the writer that Mojsisovics has drawn the lines too sharply in the discrimination of the Hallstatt species, and that there is no possibility of following this discrimination in working over similar material.

At any rate the distinction of species in the group of *Tropites subbullatus* must be entirely artificial when one has any great quantity of material. The writer has what appears to be an unbroken series, grading through *Tropites torquillus*, *T. dilleri*, *T. subbullatus*, *T. fusobullatus*, to *T. morloti*, represented, not by a few, but by a large number of specimens of each. As these all occur in the same beds, the species have no stratigraphic value, and do not mark stages in evolution.

Horizon and locality. In the Upper Trias, Karnic stage, zone of *Tropites subbullatus*, Shasta County, California, Brock Mountain, on the divide between Squaw Creek and Pitt River, six miles northeast of the Bully Hill Mine, associated with *T. subbullatus*, *T. torquillus*, *Paratropites sellai*, *P. dittmari*, *Eutomoceras sandlingense*, *Sagenites herbichi*, *Trachyceras shastense*, *Proclydonautilus triadicus*, *Halobia superba*, and many other species. This group of *Tropites* is common in the Tyrolian Alps in the same horizon and associated with the same fauna, and probably this same species occurs there too. The specific name is given in honor of Mr. J. S. Diller of the United States Geological Survey.

Tropites torquillus *Mojsisovics.*

Plate XLVI, Figs. 5-6; Plate XLVII, Fig. 4.

1893. *Tropites torquillus*, Mojsisovics, Die Cephalopoden der Hallstätter Kalke, II, p. 210, pl. ciii, figs. 1-8; pl. cvi, fig. 4.

Form involute, robust, whorl high helmet-shaped, deeply embracing, and deeply indented by the inner whorl. Umbilical shoulders angular with nearly vertical walls. Sides curving gently from the shoulder to the venter, without abdominal shoulders, so there is no separation into flanks and venter. The umbilicus is narrow and deep, exposing only the edge of the umbilical shoulders of the inner whorls.

The height of the whorl is a little more than one-half the total diameter, the width is about one and a half times the height, and the whorl is indented to one-third of its height by the inner volution. The width of the umbilicus is a little more than one-fifth of the total diameter of the shell. The surface is ornamented with fine but distinct umbilical knots, from which fine dichotomous ribs curve forward up the sides; there are also very fine spiral lines, visible only on the shell. The low central keel is not bordered by furrows.

The septa are of the usual *Tropites* type, almost exactly like those of *Tropites subbullatus*, with a divided ventral lobe, a principal lateral, and a single auxiliary above the umbilical shoulders.

This species is nearly related to *Tropites dilleri* Smith, sp. nov., but differs in its more compressed whorl and narrower umbilicus. It differs from *Tropites subbullatus* in its greater lateral compression, narrower umbilicus, and weaker sculpture.

Horizon and locality. Upper Trias, Karnic stage, zone of *Tropites subbullatus*, Shasta County, California, Brock Mountain, on the divide between Squaw Creek and Pitt River, six miles northeast of the Bully Hill Mine. This species was first found in the Tyrolian Alps, in the same horizon, and associated with the same fauna.

Genus **Paratropites** *Mojsisovics.*

1893. *Paratropites* Mojsisovics, Cephalopoden der Hallstätter Kalke, Bd. II, p. 184.
1896. *Paratropites* Mojsisovics, Beitr. Kennt. Obertriadischen Cephalopoden-Faunen des Himalaya, p. 611.

Mojsisovics gave the name *Paratropites* to what he considered as a subgenus under *Tropites*, and did not name any type, nor mention any species in the diagnosis. The first species described by him under this group, *Paratropites bidichotomus* Mojsisovics,[1] would then, according to usage, become the type, but it is neither characteristic, nor well known. The commonest and best known species of the group, *P. saturnus* Dittmar, would serve much better as the basis for the generic diagnosis, and this form, along with *P. sellai* Mojsisovics, must have been in the mind of the author as the prototype of the genus.

The form is laterally compressed, deeply embracing, and deeply indented by the inner whorls. The sides are flattened-convex, venter narrow, and the whorls are usually higher than wide. The umbilicus is narrow, the inner volutions usually being concealed. Umbilical knots are present on most species, and from these dichotomous ribs run with gentle forward curve up the flanks, and bend forward on the abdominal shoulders. On the venter is a distinct central keel, usually with furrows on each side, at which the lateral ribs end. This keel is smooth, and not crenulated by the ribs. No spines occur, and knots are known only on the umbilicus. Constrictions have not been observed on any of the numerous species of the group.

The septa are ammonitic, but not deeply digitate; they are dolichophyllic

[1] See Bibliog. 23—II, p. 234, pl. cxxvii, fig. 11.

of the *Tropites* type. The ventral lobe is divided by a shallow siphonal saddle; there are usually two principal laterals and an auxiliary present; but in some species there is only one principal lateral, and the second must be regarded as the auxiliary.

The body-chamber is long, and at maturity shows a tendency to obsolescence of the ribs, also an egression of the whorl.

Paratropites seems to have departed less from the ancestral type than *Tropites*, and this is emphasized by the fact that its young stages are much more similar to the mature forms than in that genus, where great changes take place in growth. It is not regarded as a radicle of the Tropitidæ, nor even as nearly allied to that radicle, but merely as a highly specialized group that has preserved certain characters that must have been present in the primitive stock of the Tropitidæ. *Paratropites* appears not to be any older than *Tropites;* it is known in the Karnic stage of the Upper Trias, in the Mediterranean region, in India, and in California, and according to our present knowledge it is entirely confined to that horizon. As is the case with *Tropites*, it appears unheralded by local ancestors in all three regions, so that its place of origin and its immediate ancestors are unknown. That the Tropitidæ in the stricter sense all came from a common origin can not be doubted, but at present no genera are known in the Middle Trias that could have given rise to this group.

Paratropites is represented in the Karnic stage, zone of *Tropites subbullatus*, of Shasta County, California, by two species that seem to be identical with Alpine forms, *P. sellai* Mojsisovics and *P. dittmari* Mojsisovics, as well as by a large number of species nearly allied to Mediterranean forms.

Paratropites dittmari *Mojsisovics.*

Plate XLVI, Fig. 1; Plate XLVII, Fig. 1.

1893. *Tropites (Paratropites) dittmari*, Mojsisovics, Cephalopoden der Hallstätter Kalke, II, p. 245, pl. cxv, fig. 4.

Involute, discoidal, laterally compressed. Whorls deeply embracing, and deeply indented by the inner whorl. Sides flattened-convex, with abruptly rounded umbilical shoulders, and rather gently rounded abdominal shoulders. Venter narrow and arched, surmounted by a central keel with distinct

marginal furrows. The umbilicus is narrow, almost closed at early maturity, but becoming slightly wider with increasing age. The surface is ornamented with straight ribs on the flanks, bending forward abruptly on the abdominal shoulders. These ribs bifurcate near the umbilicus and again higher up on the flanks in an irregular manner. There are no umbilical knots at maturity, or only very faint rudiments of them.

The septa are ammonitic, of the usual type of the Tropitidæ. The height of the whorl is about one-half the total diameter of the shell, and the width is two-thirds of the height. The whorl is indented to one-half its height by the inner volution, and conceals nearly all of the inner volution, except the umbilical border. The umbilicus is about one-seventh of the total diameter of the shell.

Paratropites dittmari is closely allied to *P. sellai* Mojsisovics, with which it is associated in both the Alpine province and in California; it differs from that species in the more compressed whorl, in the fewer and flatter ribs, and the obsolescence of the umbilical knots. These same characters serve also to distinguish it from *T. saturnus* Dittmar, on which also the lateral ribs are not straight, but curved broadly forward on the flanks.

Horizon and locality. Upper Trias, Karnic stage, zone of *Tropites subbullatus*, Shasta County, California, Brock Mountain, on divide between Squaw Creek and Pitt River, six miles northeast of the Bully Hill Mine. In the Tyrolian Alps it was found in the same horizon, and associated with the same fauna.

Eutomoceras sandlingense *Hauer*.

Plate XLVI, Fig. 10; Plate XLVIII, Figs. 5–6.

1849. *Ammonites sandlingensis* Hauer, Ueber neue Cephalopoden aus den Marmorschichten von Hallstatt und Aussee. Haidinger's Naturw. Abhandl. Bd. III, p. 10, pl. iii, figs. 10–12.

1866. *Ammonites sandlingensis* Dittmar, Zur Fauna der Hallstätter Kalke, p. 370.

1893. *Eutomoceras sandlingense* Mojsisovics, Cephalopoden der Hallstätter Kalke, Bd. II, p. 285, pl. cxxx, figs. 11–13, pl. cxxxi, figs. 1–11.

Involute, laterally compressed, discoidal, deeply embracing whorls, deeply impressed by the inner volutions. Umbilicus narrow, about one-eighth of the diameter of the shell, but exposing the umbilical shoulders of the inner whorls. Umbilical shoulders abruptly rounded. Sides flattened-convex, curving gently to the acute venter, with hardly any abdominal shoulders. Venter acute, narrow, surmounted by a high hollow keel, which is thinner at

the base than at the top, and without bordering furrows. The outer whorl is one-half the diameter of the shell, and the breadth is one-half of the height of the whorl. It is indented to one-third of the height by the inner volution, and conceals three-fourths of that volution.

Surface ornamented with numerous fine, but distinct, sickle-shaped ribs, that curve backward on the flanks and forward on the shoulders to the base of the keel, where they become obsolete. These ribs are either single or dichotomous, the division taking place nearly half way up the flanks. The ribs are rounded, low, and narrower than the intercostal spaces; there are about sixty to a revolution on the mature shell. In addition to these there are fine spiral lines that show distinctly on the cast as well as on the shell. Around the umbilicus there is a row of small knots, the remnant of coarse umbilical ribs in the *Tropites* stage of growth.

The septa are ammonitic, but comparatively simple, lobes and saddles all digitate, but not deeply so. External lobe divided by a shallow siphonal saddle into two short branches. First lateral lobe broader and deeper; second lateral less than half the size of the first; auxiliary shallow and composed of two or three indentations on the umbilical shoulder. The anti-siphonal lobe is flanked by three internal laterals.

The young of *Eutomoceras sandlingense* are robust, and not discoidal, resembling *Paratropites;* they can, however, be distinguished from that genus by their sharper venter. In the earlier stages the sculpture is much rougher than at maturity, resembling that of *Tropites;* but in *Eutomoceras sandlingense* the ribs appear before the keel, at the diameter of about one millimeter, while the keel does not appear until a diameter of two and seven-tenths millimeters is reached. In all species of *Tropites* and *Paratropites* examined by the writer the keel develops before the lateral ribs. From the development of this species it is clear that *Paratropites* connects it with *Tropites.* The earlier larval stages are like *Gastrioceras* of the Carboniferous, and probably indicate derivation from that genus.

The Californian specimens show as much variation as do those of the Alps, there being no constancy in the size and number of the ribs.

Mojsisovics assigned this species to Hyatt's genus *Eutomoceras*, which is nearly allied to *Hungarites* under the *Ceratitoidea;* but all its characters point to an origin from the Tropitidæ.

Horizon and locality. Upper Trias, Karnic stage, zone of *Tropites subbullatus*, Brock Mountain, divide between

Squaw Creek and Pitt River, about six miles northeast of the Bully Hill Mine. In the Tyrolian Alps it occurs in the same horizon, and with the same fauna.

Genus Sagenites *Mojsisovics.*

1879. *Sagenites* Mojsisovics, Vorläufige kurze Uebersicht der Ammoniten Gattungen, etc., p. 141.

1893. *Sagenites* Mojsisovics, Cephalopoden der Hallstätter Kalke, Bd. II, p. 155.

1896. *Sagenites* Mojsisovics, Beitr. Kennt. Obertriadischen Cephalopoden-Faunen des Himalaya, p. 608.

Type, *Ammonites reticulatus* Hauer.

Subglobose, somewhat compressed laterally, sides rounded, venter highly arched. No abdominal shoulders. Whorls involute, deeply embracing, increasing rapidly in height. Umbilicus narrow, but open and deep. Body-chamber long. Sculpture consisting of dichotomous folds or ribs, which cross the venter, but become weak on that part of the shell. In addition to these folds there may be spiral lines or ridges; and in one group there occur short spines arranged in spiral rows on the ribs.

The septa are ammonitic, complex, and deeply digitate.

Mojsisovics divides *Sagenites* into three groups: 1. *Sagenites inermes*, 2. *Sagenites reticulati*, and 3. *Sagenites spinosi*. The last group he designates as the subgenus *Trachysagenites*, with *Sagenites erinaceus* Dittmar as the type.

The *Sagenites inermes* and *Trachysagenites* appeared in the Karnic horizon of the Upper Trias, the latter becoming extinct at the end of this stage, and the former living on into the Noric stage, in which the *Sagenites reticulati* appeared for the first time. The genus *Sagenites* s. str. is not known in America, but it is represented by two species of the subgenus *Trachysagenites*, *S. erinaceus* Dittmar and *S. herbichi* Mojsisovics.

Sagenites (Trachysagenites) herbichi *Mojsisovics.*

Plate XLVI, Figs. 7–8; Plate XLVII, Figs. 5–6.

1893. *Sagenites (Trachysagenites) herbichi*, Mojsisovics, Cephalopoden der Hallstätter Kalke, II, p. 180, pl. ci, fig. 3; pl. cii, figs. 1–6.

Form subglobose, somewhat compressed laterally, robust, involute. Whorl highly arched, high, helmet-shaped, deeply embracing, increasing rapidly in height, and not de[illegible]ented by the inner volutions. Sides convex,

curving to the broad venter without any marked abdominal shoulders. Umbilical shoulders abruptly rounded, with the inner walls steep. Umbilicus deep and narrow, but exposing the umbilical shoulders of the inner whorls, and becoming wider with age. Body-chamber long, apparently comprising at least an entire revolution.

Surface ornamented with numerous closely set radial ribs, that run nearly straight from the umbilicus across the venter, usually dividing on the flanks. On the ribs are spiral rows of short spines or knots, varying from nine to thirteen rows on each side, showing only on the outer shell and not on the cast. This sculpture is the same over all parts of the whorl, and there is no interruption on the venter nor any ventral furrow. This character easily distinguishes *Trachysagenites* from *Trachyceras*, with which it is associated, and with which it has often been confused. The spiral arrangement of the spines separates it from *Halorites*.

The septa are ammonitic, more deeply digitate than is usual in the *Tropitoidea*. The external lobe is divided by a shallow siphonal saddle into two short branches. The first lateral lobe is long, rather broad, and divided at the end into two branches. The second lateral is shorter and narrower, but also digitate. On the umbilical shoulder is a distinctly individualized auxiliary lobe, not unlike the second lateral, but smaller. The antisiphonal lobe is long and narrow, flanked by two similar lobes on each side.

This species grew to a considerable size, specimens of nearly two hundred millimeters diameter having been found, and the relative measurements remain remarkably constant from adolescence to maturity, except that in adolescence the whorl is slightly broader in proportion to the height, the involution somewhat less, and the umbilicus slightly broader.

The young shells are subglobose and nearly smooth, resembling the Glyphioceratidæ of the Carboniferous. The lateral ribs appear at the diameter of four millimeters, and the spiral rows of knots at five millimeters. The septa pass from the goniatite to the ammonite stage at a little under three millimeters.

Sagenites herbichi Mojsisovics is very like *S. erinaceus* Dittmar, as figured by Mojsisovics in "Cepholopoden der Hallstätter Kalke", II, plate c, figures 2–4, but differs from that species in its greater lateral compression, more numerous spiral rows of knots, and much more numerous and finer radial ribs; also in *S. herbichi* the lobes are shorter and broader, the second lateral is small and scarcely divided, and the auxiliary is represented only by a small notch on the umbilical shoulders.

Sagenites herbichi is common in the Upper Trias, Karnic stage, zone of *Tropites subbullatus* of the Alps. In California it is common in the same horizon, associated with *Tropites subbullatus*, *Paratropites sellai*, *Halobia superba*, etc., in Shasta County, on Brock Mountain, on the divide between Squaw Creek and Pitt River, about six miles northeast of the Bully Hill Mine. A similar and probably identical species has been found in the Himalayas in India, so this form may be considered as characteristic of the Karnic stage.

Genus **Proclydonautilus** *Mojsisovics*.

1902. *Proclydonautilus*, Mojsisovics, Das Gebirge um Hallstatt, Supplement-Heft, p. 207.

Type, *Nautilus griesbachi* Mojsisovics.

Generic characters: Form involute, with high, rounded whorls, nearly smooth shell, narrow umbilicus, and nearly central siphuncle. The septa are divided into several lobes and saddles. The broad ventral saddle is divided by a shallow funnel-shaped lobe; there is also a broad and deep lateral lobe. The internal part of the septa shows no lobes nor saddles.

The young stages are like the Carboniferous genus *Coloceras* Hyatt (*Nautilus globatus* Meek & Worthen), and the transition from the Paleozoic to the Triassic type of septa is very gradual. Mojsisovics[1] formerly classed *Nautilus triadicus* under his genus *Clydonautilus*, from which, however, it may easily be distinguished by having one less lateral lobe, and a rounded instead of angular whorl, and by the shape of the inner volutions. The writer is not of the opinion that *Proclydonautilus* belongs to the same group as *Clydonautilus*. This genus is common in the Upper Trias of the Mediterranean region, India and California.

Proclydonautilus triadicus *Mojsisovics*.

Plate XLVI, Fig. 2; Plate XLVII, Fig. 2.

1873. *Nautilus triadicus*, Mojsisovics, Das Gebirge um Hallstatt, Bd. I, p. 27, pl. xiv, figs. 1-4.

1882. *Clydonautilus triadicus*, Mojsisovics, Cephalopoden d. Mediterranen Triasprovinz, p. 281.

1902. *Proclydonautilus triadicus*, Mojsisovics, Das Gebirge um Hallstatt, Supplement-Heft, p. 209.

[1] See Bibliog. 21—p. 281.

Involute, somewhat compressed laterally, high-whorled, with broadly rounded flanks and venter, without any angle on either. Umbilicus completely closed; umbilical shoulders broadly rounded. The whorl is slightly broader than high, the greatest breadth being even with the top of the inner whorl. The height of the whorl is two-thirds of the total diameter. The siphuncle lies a little below the center. The surface is smooth, there being no ornamentation except the exceedingly fine radial striæ of growth, which bend backwards on the venter, forming a broad hyponomic sinus.

The septa are sinuous, showing both lobes and saddles. The broad and deep ventral saddle is divided by a narrow and shallow abdominal lobe; the lateral lobe is long and rather broad; on the umbilicus there is a second lateral lobe, shallow and broad. The internal septum is nearly straight.

Relative dimensions of the adult shell:

Diameter	1.00
Height of last whorl	0.66
Height of last whorl from preceding	0.46
Width	0.70
Involution	0.20
Width of umbilicus	0.00

The largest specimen found had a diameter of ninety-seven millimeters; the average size of several mature specimens was about seventy millimeters.

In the youngest stages there is no lobe nor saddle, the septum being straight, and the shape is globose. At this stage the shell corresponds to *Coloceras* Hyatt (*Nautilus globatus* Meek & Worthen) of the Carboniferous. At the diameter of seven millimeters, the ventral lobe begins to develop, and at ten millimeters the lateral lobes and saddles are visible. At this stage the whorl ceases to be subglobose, and becomes higher. At twenty-five millimeters the shell has all the characters of maturity, and from then on changes only in size.

The ontogeny of this species enables us to connect a highly specialized Mesozoic group with the Paleozoic radicle.

Horizon and locality. Upper Trias, Karnic stage, zone of *Tropites subbullatus*, Shasta County, California, on the divide between Squaw Creek and Pitt River, about six miles northeast of the Bully Hill Mine, near the trail over Brock Mountain. It was first found in this same horizon near Hallstatt in the Tyrolian Alps, associated with a very similar fauna.

Genus Halobia *Bronn.*

Type, *Halobia salinarum* Bronn.

Generic characters (as defined by Mojsisovics, Ueber die Triadische Pelecypoden-Gattungen Daonella und Halobia, Abhandl. k. k. geol. Reichsanstalt, Wien, Bd. VII, Heft 2, 1874, p. 23): Bivalve, inequilateral, beak conical, moderately high, situated anterior to the middle of the hinge area, which is long, straight and taking up the full length of the shell. Valve wider than high. Anterior ear, on both valves, separated from the rest of the shell by a depression, and distinguished by the change in ornamentation. No byssal notch. Radial ribs over the whole surface, and usually concentric wrinkles.

Halobia s. str. begins in the lower Ladinic stage, top of the Middle Trias, but becomes common first in the Karnic stage of the Upper Trias, to which horizon it is chiefly confined. It is found in the Upper Trias of the Alps, India, Spitzbergen, the Indian Ocean, and California. It is rare in the Noric stage. *Halobia* developed out of *Daonella*, with which it is connected by transitional forms.

Halobia superba *Mojsisovics.*

Plate XLVIII, Figs. 1-2.

1874. *Halobia superba*, Mojsisovics, Ueber die Triadischen Pelecypoden-Gattungen Daonella und Halobia, p. 30, pl. iv, figs. 9-10.

Beaks rather high and conical. Form highly arched, though usually pressed flat, wider than high. Surface ornamented with fine radial ribs, numerous and close-set, with interspaces narrower than the ribs. The ribs bifurcate, and are not grouped in bundles, strongest on the arch of the valve, weakest on the front and rear. At the height of 12-15 mm. the ribs bend suddenly forward at a strong concentric wrinkle, and then bend as suddenly back again. This is characteristic on all specimens, and marks the time of attachment of the shell. Concentric wrinkles faint but distinct, strongest on the young shells. Anterior ear distinct, cut off from the shell by a furrow and change in ornamentation.

The size at which the angle in the ribs forms is usually smaller than that given by Mojsisovics, twelve instead of fifteen millimeters, but this character is not sufficient for specific discrimination. Several Californian specimens showed height of fifteen millimeters at the angle.

The beak has only concentric wrinkles and no ribs; this stage probably corresponds to the genus *Posidonomya*, and lasts up to a diameter of two and five-tenths millimeters,

when the ribs begin, and the change to *Daonella* takes place. The *Daonella* stage lasts up to a diameter of a little over five millimeters, when the anterior ear develops.

Halobia superba is closely allied to *H. fallax* Mojsisovics, but differs from it in the slightly coarser ribs, and the smaller size at which the angle in the ribs occurs. It is also nearly related to *H. fascigera* Bittner,[1] from the Karnic stage of India; but the Indian species is as high as wide, and more oblique in form, and the ribs are distinctly bundled. The beaks are lower and scarcely projecting. The ribs and concentric wrinkles appear to be stronger than on *H. superba*.

Horizon and locality. Upper Trias, Karnic stage, zone of *Tropites subbullatus*, of the Alps, and Shasta County, California. It is common in this horizon in Shasta County, on the divide between Squaw Creek and Pitt River. The figured specimens came from Brock Mountain, six miles northeast of the Bully Hill Mine, near the trail across from Madison's to Brock's Ranch. The species is most abundant in the calcareous shales just below the limestone with *Tropites subbullatus*, but it is also quite common in the limestone, where specimens with a width of one hundred ten millimeters and height of about seventy millimeters were found.

Subgenus **Daonella** *Mojsisovics.*

1874. *Daonella*, Mojsisovics, Ueber die Triadischen Pelecypoden-Gattungen Daonella und Halobia, p. 7.

Type, *Daonella lommeli* Wissmann.

Equivalve, inequilateral, rounded in front and rear; beaks near the middle of the hinge-line, and scarcely projecting above it. Surface of the whole shell ornamented with radial bifurcating ribs. There are no ears, and this is the chief character that separates *Daonella* from *Halobia*.

Daonella appeared first in the lower Muschelkalk as an offshoot from *Posidonomya*, but became common first in the upper Muschelkalk, and lived on into the Karnic stage. It seems to grade over into *Halobia*, so that most writers

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[1] Pal. Indica, Ser. XV, Himalayan Fossils, Vol. III, Part 2, 1899, p. 45, pl. vii, fig. 15.

have made no distinction between the two groups. But since the two groups have a rather distinct stratigraphic range, and since the extremes can easily be separated, the writer prefers to give at least subgeneric rank to *Daonella*.

Daonella dubia *Gabb.*

Plate XLIV, Fig. 5.

1864. *Halobia dubia*, Gabb, Pal. Calif. Vol. I, p. 30, pl. v, figs. 28 *a–b*.
1874. *Daonella dubia*, Mojsisovics, Ueber die Triadischen Pelecypoden-Gattungen Daonella und Halobia, p. 22.
1877. *Halobia (Daonella) lommeli*, Meek, U. S. Geol. Expl. Fortieth Parallel, Vol. IV, p. 100, pl. x, fig. 5.

This species, which Meek united with *Daonella lommeli*, differs from the Alpine form in the coarser ribs bundling in pairs, instead of in threes or more. The concentric wrinkles are stronger, and the beak is higher, projecting above the hinge-line. There is no ear on the shell, but the hinge-line is long and straight, and near it the ribs become fainter. The height is about two-thirds of the length, as is the case with *D. lommeli*. The greatest length observed was about eighty millimeters. The figure given by Gabb is of a negative cast, reversing the ribs and interspaces, and thus not giving a correct idea of the ornamentation. Meek's figures are correct, but his specimens were poor.

Daonella dubia is nearest to *D. paucicostata* Tornquist[1] from the zone of *Ceratites nodosus*, but is more highly arched, and has a more prominent beak. The radial furrows of *D. paucicostata* begin at from five to nine millimeters from the beak, and the ridges are said to be simple, without bifurcations. Tornquist's figure 2 looks very like *D. dubia*, but his description does not agree. *D. indica* Bittner[2] resembles *D. dubia*, but has no bundling of the ribs, which are also slightly finer, and the concentric wrinkles coarser. *Daonella* conf. *indica*, Bittner[3] is nearer to *D. dubia*, and might even be identical with it.

[1] Zeitschr. Deutsch. Geol. Gesell., 1898, Bd. L, Heft 4, (II Beitrag), p. 673, pl. xxii, figs. 1–4.

[2] Pal. Indica, Ser. XV, Vol. III, Part 2, p. 39, pl. viii, figs. 4–11.

[3] L. c. pl. viii, fig. 12.

Daonella dubia is common in the *Daonella* beds, upper part of the Middle Trias, in the West Humboldt Range in Nevada, in Buena Vista, Cottonwood, and American canyons. It was also found by the Geological Survey of California under J. D. Whitney at New Pass, in the Desatoya Mountains, Nevada.

The figured specimens came from the divide between Troy Canyon and the south fork of American Canyon, West Humboldt Range, associated with *Beyrichites rotelliformis*, *Anolcites meeki*, *A. whitneyi*, *Ceratites nevadanus*, *Gymnotoceras blakei*, *Sageceras gabbi*, *Celtites halli*, and many other forms characteristic of the Middle Trias.

Genus **Pseudomonotis** *Beyrich.*

1862. *Pseudomonotis*, Beyrich, Ueber zwei neue Formengruppen aus der Familie der Aviculiden, Zeitschr. Deutsch. Geol. Gesell. Bd. XIV, p. 9.
1886. *Pseudomonotis*, Teller, in Mojsisovics, Arktische Triasfaunen, p. 105.
1900. *Pseudomonotis*, Bittner, Ueber Pseudomonotis Telleri, und dessen Verwandte, Jahrb. k. k. geol. Reichsanstalt, Wien, Bd. L., 1900, pp. 559-592.

Type, group of *Pseudomonotis ochotica* Keyserling.

Inequivalve, inequilateral, form oblique, higher than wide, hinge-line straight and long. Left valve arched, right valve flatter; ear on both valves distinct, with byssal notch in right valve. Radial ribs, with concentric wrinkles or striæ.

Beyrich named no type for the genus, but said that the species composing it differed little from *Monotis;* accordingly, Teller and Bittner have reserved *Pseudomonotis* s. str. for the group of *P. ochotica*. The genus, in the broader sense, has representative species from Permian through the Mesozoic; but the species of the genus as limited by Teller and Bittner are confined to the Trias, and are especially characteristic of the Upper Trias, Noric stage, in the Arctic-Pacific and the American regions. The group of *Pseudomonotis ochotica* is found in the Noric horizon in New Caledonia, Japan, New Zealand, Siberia, Alaska, British Columbia, California, Nevada, Peru, and Colombia, with nearly related species in all these places, always above the Karnic stage and near the top of the Trias.

Pseudomonotis subcircularis *Gabb.*

Plate XLIX, Figs. 1-3.

1864. *Monotis subcircularis*, Gabb, Pal. Calif. Vol. I, p. 31, pl. vi, figs. 29, 29*a*.

1886. *Pseudomonotis subcircularis*, Teller, in Mojsisovics, Arktische Triasfaunen, p. 113.

Form and ornamentation extremely variable; pectinoid, inequilateral, inequivalve, oblique, broadly ovate, with the greatest height towards the rear. Front broadly rounded, rear sloping gently up to the hinge-line. Left valve highly arched, right valve flatter. Hinge-line straight, and a little more than one-third of the total length of the shell. The length of the shell is slightly greater than the height. Anterior ear with byssal notch on right valve,—the character that distinguishes this species from *Monotis*. Posterior ears alike on both valves.

Surface ornamented with rather coarse radial ribs about 26 in number, and between most of these there is a finer intercalary rib. The principal ribs begin near the beak, but the intercalaries make their appearance at a height of about 15 mm. The interspaces are considerably wider than the ribs. There are also fine concentric wrinkles or striæ of growth over the entire surface.

In youth the shell is much more elliptical in shape, is longer than high, and the ribs are much fewer, as well as coarser in proportion to the size of the shell.

This species is nearly allied to the variety described by Teller[1] as *Pseudomonotis ochotica* Keyserling, var. *densistriata*, and indeed appears to be identical with it. The writer is, however, by no means convinced that all the so-called varieties of *Pseudomonotis ochotica* really belong to one species. Certainly their discrimination is not on a par with that of the ammonites nor of the members of the Pectinidæ.

The writer has also found, in the *Pseudomonotis* beds of California and Nevada, varieties with fewer and coarser ribs, more like the typical form of *P. ochotica*, as figured by Teller,[2] and it is quite possible that there may be in America, as is said to be the case in Siberia, a transition between these varieties. At present the writer is unable to decide this, and so merely the typical *Pseudomonotis subcircularis* is figured.

[1] Arktische Triasfaunen, p. 116, pl. xvii, figs. 7-15.

[2] Ibid. pl. xvii, figs. 1-6.

Horizon and locality. Upper Trias, Noric stage (above the limestone with *Tropites subbullatus*), Genesee Valley, Plumas County, California, Brock Mountain, on divide between Squaw Creek and Pitt River, Shasta County, California; and in Muttleberry Canyon, nine miles southeast of Lovelock, Humboldt County, Nevada, in a branch of the West Humboldt Range.

The figured specimens came from Genesee Valley, from the so-called Swearinger slates of Diller, near Robinson's Ranch, Plumas County, California.

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EXPLANATION OF PLATE XL.

Plate xl shows the distribution of marine Triassic sediments and the probable distribution of land and sea in the United States during the Trias. Columnar sections of the Trias are given, showing the approximate thickness and age of the marine sediments at the six localities where they have been studied in detail.

1. Inyo Range, California, with about a thousand feet of calcareous shales and limestones with a typical Lower Triassic fauna, surmounted by a few hundred feet of shales and limestones, with a fauna referred to the base of the Middle Trias.

2. Santa Ana Mountains, California, showing a few hundred feet of limestones with a fauna probably of Lower Triassic age.

3. Aspen Mountains, Idaho, with about eight hundred feet of sandstones and impure limestones with a typical Lower Triassic fauna.

4. Humboldt Range, Nevada, showing about eight hundred feet of shaly limestones with a Middle Triassic fauna, and about two thousand feet of calcareous beds of the Upper Trias.

5. Genesee Valley, Plumas County, California, showing about five hundred feet of limestones, with an Upper Triassic fauna.

6. Shasta County, California, showing about fifteen hundred feet of siliceous shales with Middle Triassic fossils, overlain by about five hundred feet of calcareous sediments with a rich Upper Triassic fauna.

It is probable that the area shown on the map was mostly covered by sea during the Lower Trias, but that the waters retreated gradually westward, until near the close of the Trias only a small remnant was left.

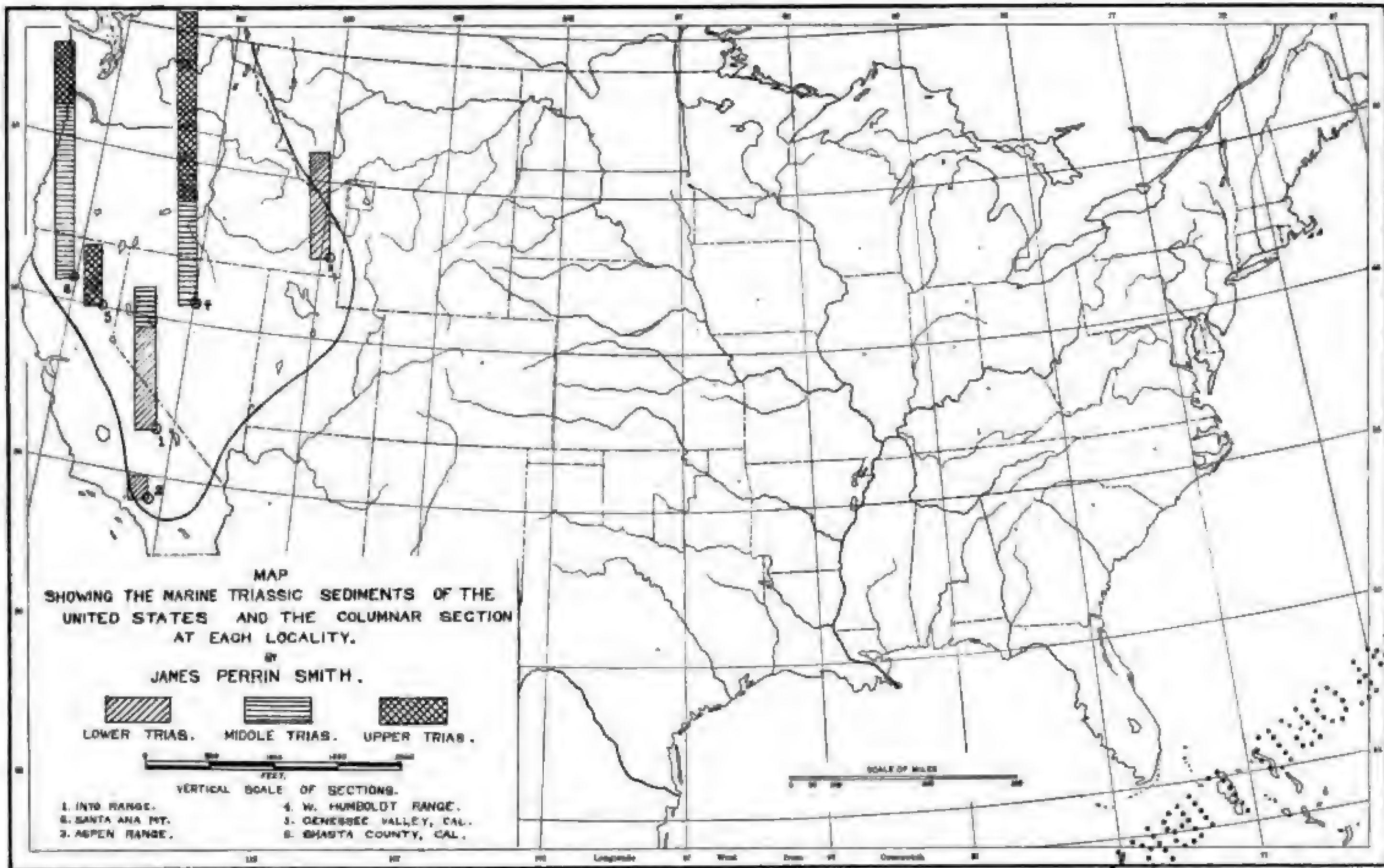
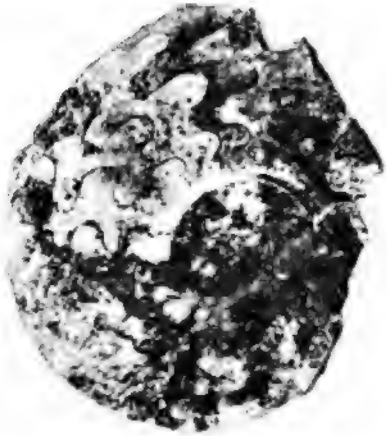


PHOTO-LITH. BRITTON & REY, S.F.

EXPLANATION OF PLATE XLI.

Lower Trias, *Meekoceras* beds, Wood Canyon, nine miles east of Soda Springs, Aspen Mountains, Idaho.

		PAGE
Figs. 1-3.	*Meekoceras (Koninckites) mushbachanum* WHITE......	376
Figs. 4-6.	*Meekoceras (Gyronites) aplanatum* WHITE............	373



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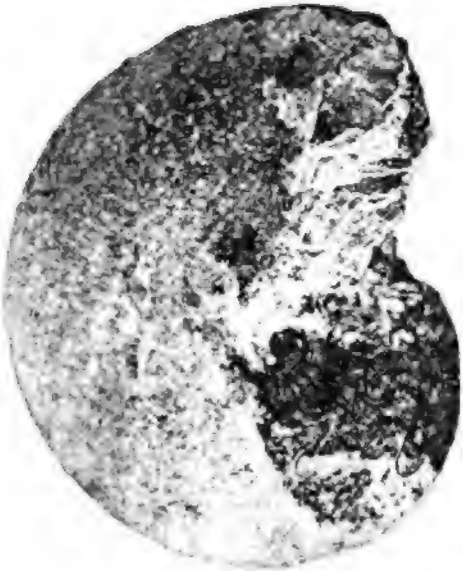
EXPLANATION OF PLATE XLII.

Lower Trias, *Meekoceras* beds, Wood Canyon, nine miles east of Soda Springs, Aspen Mountains, Idaho.

		PAGE
Figs. 1-4.	*Meekoceras gracilitatis* WHITE	370
Fig. 5.	*Flemingites russelli* HYATT & SMITH, ms.	378



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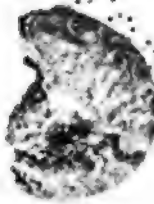

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EXPLANATION OF PLATE XLIII.

		PAGE
Figs. 1-2.	*Meekoceras (Koninckites) mushbachanum* WHITE, front view and septa of specimen shown on plate xli, figure 1	376
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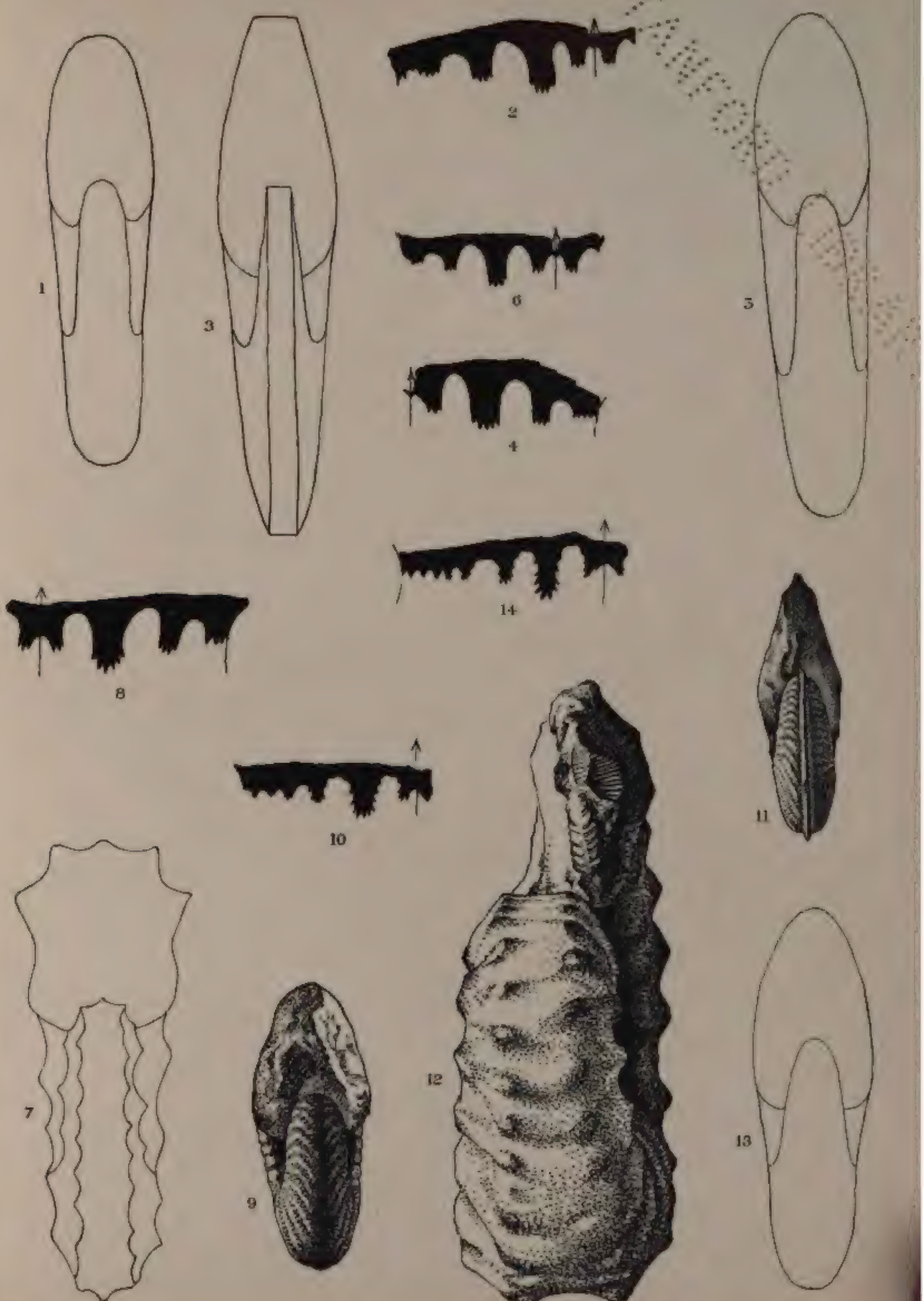
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EXPLANATION OF PLATE XLIV.

Middle Trias, *Daonella* beds, on divide between Troy Canyon and the south fork of American Canyon, West Humboldt Range, Nevada.

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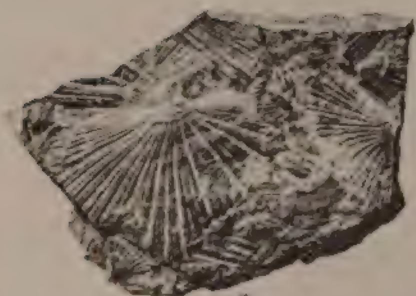

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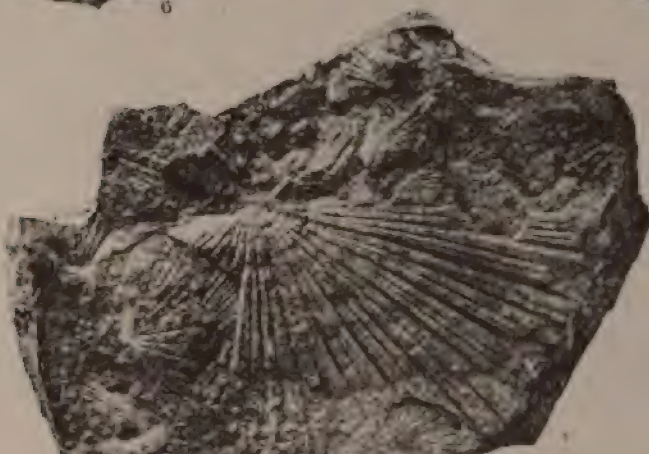

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EXPLANATION OF PLATE XLV.

Middle Trias, *Daonella* beds, on divide between Troy Canyon and the south fork of American Canyon, West Humboldt Range, Nevada.

		PAGE
Figs. 1-2.	*Trachyceras (Anolcites) hyatti* SMITH, sp. nov.........	389
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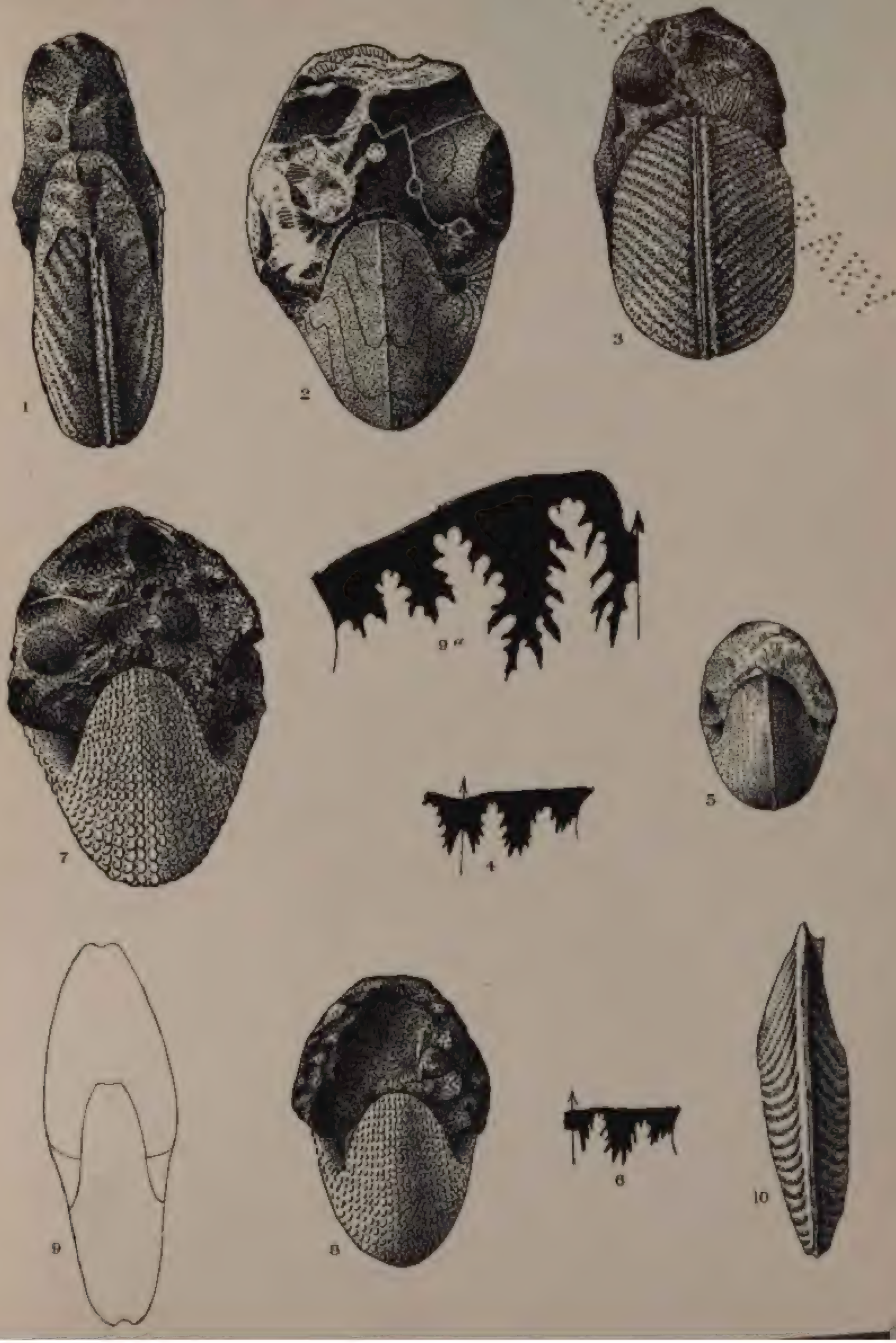
EXPLANATION OF PLATE XLVI.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EXPLANATION OF PLATE XLVII.

Upper Trias, Zone of *Tropites subbullatus*, Karnic stage, Brock Mountain, on divide between Squaw Creek and Pitt River, six miles northeast of Winthrop, Shasta County, California.

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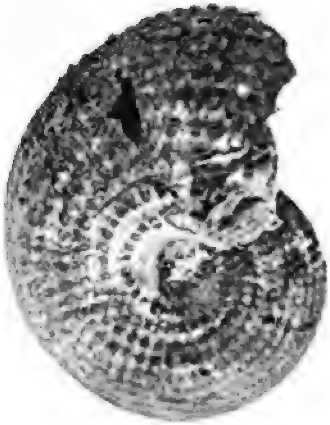

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EXPLANATION OF PLATE XLVIII.

Upper Trias, Zone of *Tropites subbullatus*, Karnic stage, Brock Mountain, between Squaw Creek and Pitt River, six miles northeast of Winthrop, Shasta County, California.

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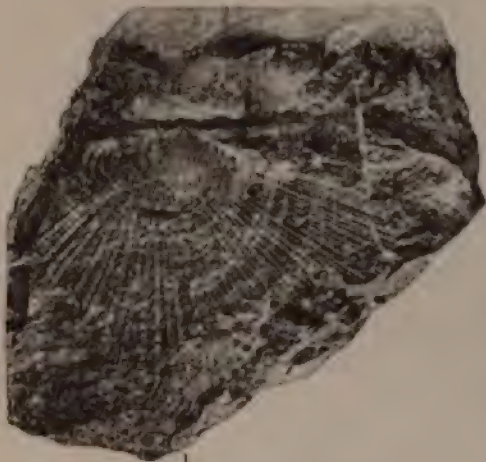

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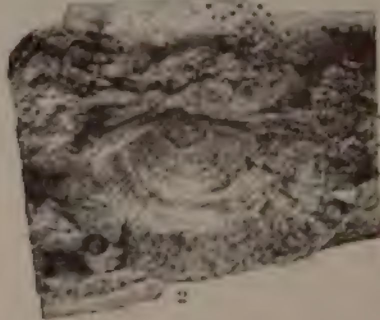

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J. P. SMITH DEL.

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EXPLANATION OF PLATE XLIX.

Upper Trias, Noric stage, Pseudomonotis beds, Robinson's (Gifford's) Ranch, Plumas County, California.

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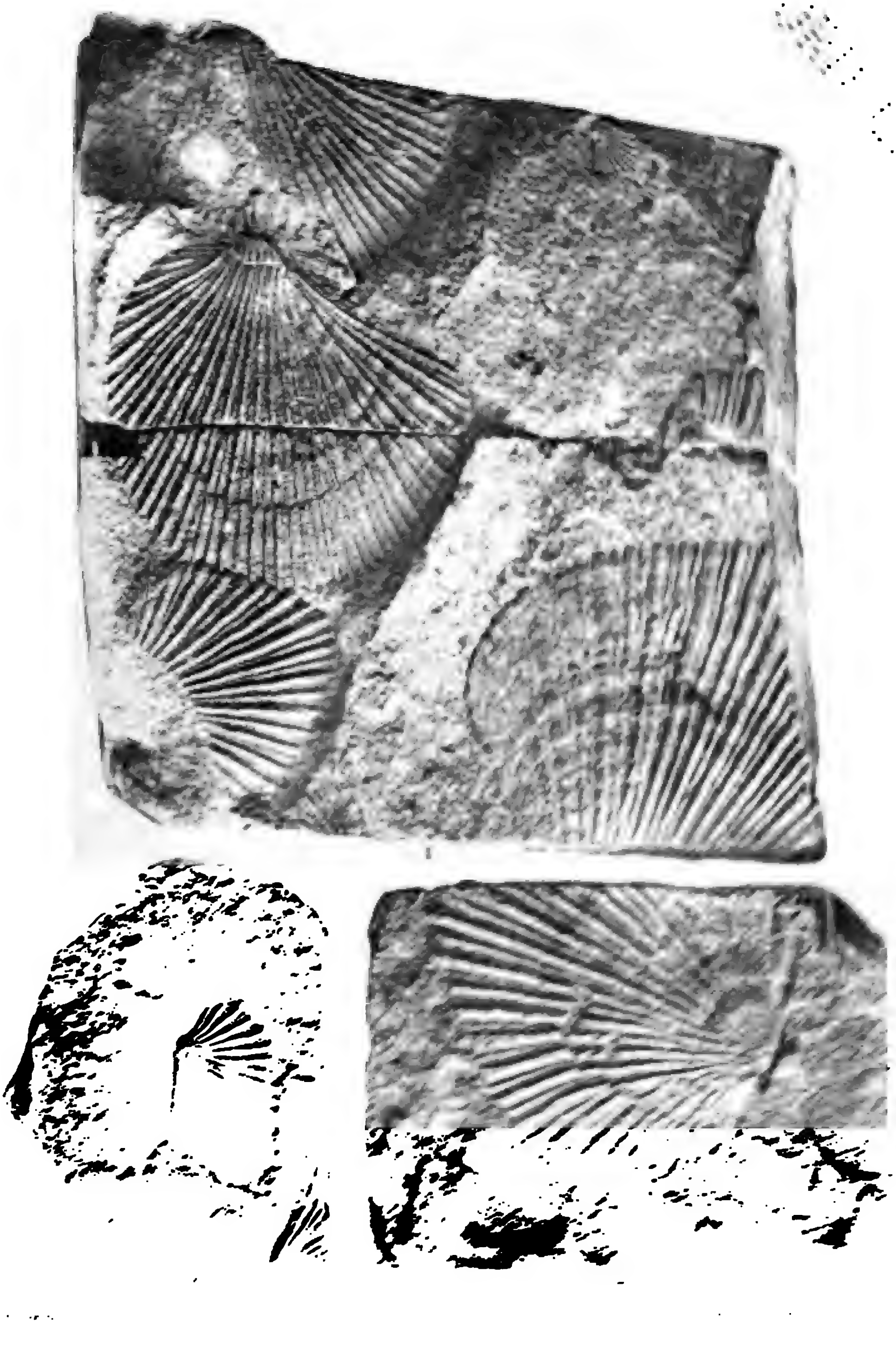
Fig. 1 showing adult left valve; fig. 2 showing adult right valve, with the byssal ear; fig. 3, young right valve, with byssal ear.



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New names in **heavy-faced** type.